APPENDIX A: RISK ASSESSMENT CRITERIA

Human Health Risks

The BSMT developed risk assessment criteria for human health risks that included three factors:

- An estimated likelihood of a risk's occurrence based on current countermeasure practices;
- The consequences to crew health and performance should the risk occur;
- The overall current status of risk mitigation (the "readiness" or maturity level of the technology or countermeasure).

Each of these factors was evaluated on a three-part scale (high, moderate and low). One factor was judged for its effect on in-flight health, in-flight performance and post-mission health and performance, with the most severe outcome used as the consequence rating. For CRL/TRL (**Error! Reference source not found.**), readiness levels 1-3 represent low, levels 4-6 represent moderate and 7-9 represent high mitigation status.

	Low	Moderate	High
Human Health	<0.001	0. 001-0.01	>0.01

Table A-1 Estimated Likelihood Scale (with Current Countermeasures)

Severity of Consequences

Types of Consequences	Low	Moderate	High
Crewmember Health In-flight	No More Than Temporary Discomfort	Short-Term Incapacitation or Impairment	Death, Significant Health Issue Requiring mission Abort, or Long-Term Incapacitation or Impairment
Crewmember Performance	Delays of Mission Objectives	Loss of Some Mission Objectives	Inability to Perform Critical Mission Functions, or Total loss of Mission Objectives
Crewmember Health Post-mission	Limited increase in Post-mission Rehabilitation	Impairment but No Long Term Reduced Quality of Life	Significant Permanent Disability or Significantly Reduced Lifespan, or Significant Long Term Impairment or Reduced Quality of Life

Table A-2 Consequences to Crew Health and Performance

System Performance/Efficiency Risks

The BSMT also developed risk assessment criteria for systems performance risks that reflected improved efficiencies. Efficiencies reflect reduction in utilization of in-flight resources (crew time, power, mass, volume, necessity for re-supply, etc.) for an equivalent task.

APPENDIX B: RISK DATA SHEETS

Human Health and Countermeasures

Risk Title: Accelerated Bone Loss and Fracture Risk

Primary Risk Area	Bone		
Risk Number	1		
Risk Description	Human work performance failure due to injury. Compromised mission objectives.		
Context/Risk Factors	Age, gender, baseline BMD, nutrition, muscle loss		
Specific current countermeasure(s) or mitigation(s)	Bisphosphonate, resistive exercise, gravity-related exercise activity, nutrition		
Specific projected countermeasure(s) or mitigation(s)	TBD		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Yellow	Green	Yellow
Justification/Rationale for Risk	TBD	TBD	TBD
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
1a.	What is the relative risk of sustaining a traumatic and/or stress fracture for a given decrement in bone mineral density or alteration in bone geometry in an astronaut-equivalent population who are physically active? [ISS 3 Moon 5 Mars 1]		
1b.	Will a period of rapid bone loss in hypogravity be followed by a slower rate of loss approaching a basal bone mineral density? What are the estimated site-specific fracture risks as one approaches this minimal BMD? [ISS 2 Moon 5 Mars 1]		
1c.	Is there an additive or synergistic effect of gonadal hormone deficiency in men or women on bone loss during prolonged exposure to hypogravity? [ISS 1 Moon 5 Mars 5]		
1d.	What pharmacological agent(s) will most effectively minimize the decrease in bone mass with extended exposure to hypogravity? [ISS 1 Moon 5 Mars 1]		
1e.	What are the specifics of the optimal exercise regimen with regard to mode, duration, intensity and frequency, to be followed during exposure to hypogravity so as to minimize decreases in bone mass? Is impact loading an essential element and, if so, how can it be produced in hypogravity? [ISS 1 Moon 3 Mars 1]		
1f.	What combination of exercise and a pharmacological agent(s) will prevent bone loss during exposure to hypogravity? [ISS 1 Moon 5 Mars 1]		

1g.	What are the important predictors for estimating site-specific bone loss and fracture risk during hypogravity exposure, especially with reference to ethnicity, gender, age, baseline bone density and geometry, nutritional status, fitness level and prior microgravity exposure? [ISS 1 Moon 5 Mars 1]
1h.	Does the hypogravity environment change the nutritional requirements for optimal bone health? [ISS 3 Moon 3 Mars 2]
1i.	What diagnostic tools can be utilized during multi-year missions to monitor and quantify changes in bone mass and bone strength? [ISS 2 Moon 5 Mars 1]
1j.	What systemic adaptations to hypogravity are important contributory factors to bone loss, evaluations of which are essential to effective countermeasure development (e.g., fluid shifts, altered blood flow, immune system adaptations)? [ISS 3 Moon 5 Mars 2]
1k.	Are hypogravity-induced changes in bone density, geometry and architecture reversible upon encountering partial Gravity exposure, or on return to full gravity (1-G)? [ISS 1 Moon 5 Mars 1]
1l.	What regimen (exercise, pharmacological or biomechanical including impact loading or AG exposure) will most effectively hasten restoration of bone mass and bone strength (geometry and architecture) to pre-flight values in returning crewmembers? [ISS 2 Moon 5 Mars 2]
Related Risks	TBD
Important References	Shapiro JR, Schneider V. Countermeasure development: future research targets. J Gravit Physiol. 2000 Jul;7(2):P1-4.
	Heer M, Kanips N, Biener C, Korr C, Boerger A, Zittenman A, Stehle P, Drummer C. Calcium metabolism in microgravity. Eur J Med Res. 1999 Sep 9;4(9): 357-60 Review.
	Jennings RT, Bagian JP. Musculoskeletal injury review in the U.S. space program. Aviat Space Environ Med. 1996 Aug; 67(8): 762-6.
	Schneider SM, Amonette WE, Blazine K, Bentley J, Lee SM, Loehr JA, Moore AD Jr, Rapley M, Mulder ER, Smith SM.. Training with the International Space Station interim resistive exercise device. Med Sci Sports Exerc. 2003 Nov;35(11):1935-45.
	Bikle DD, Sakata T, Halloran BP. The impact of skeletal unloading on bone formation. Gravit Space Biol Bull. 2003 Jun;16(2):45-54. Review.
	Cancedda R, Muraglia A. Osteogenesis in altered gravity. Adv Space Biol Med. 2002;8:159-76. Review.
	Cena H, Sculati M, Roggl C. Nutritional concerns and possible countermeasures to nutritional issues related to space flight. Eur J Nutr. 2003 Apr;42(2):99-110. Review.

Risk Title: Impaired Fracture Healing

Primary Risk Area	Bone
Risk Number	2
Risk Description	Impaired Fracture Healing
Context/Risk Factors	Risk factors will differ for major skeletal fracture vs. minor, stress related fractures. Rapid bone loss is progressive, work environment and nutritional environment are factors.
Specific current countermeasure(s) or mitigation(s)	Minimize bone loss to lessen fracture risk, orthopedic procedures, rehabilitation procedures, ultrasound and electrical stimulation. Major fracture-return crew (ISS and Moon). Possibly biochemical/pharmacological intervention to hasten fracture healing for Mars.

Specific projected countermeasure(s) or mitigation(s)	Biomechanical measure to promote healing in relatively short time frame (ISS). Application of novel locally active agents to facilitate fracture healing in concert with biomechanical stimulation (Moon and Mars).		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Green	Green	Red
Justification/Rationale for Risk	Major fracture-Operational disruption for prolonged time. Minor fracture site-Minor operational disruption.		Major fracture-Operational disruption for prolonged time, fracture- related complications including immobility might risk death. Minor fracture site-Minor operational disruption
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
2a.	Is the rate of fracture healing and the integrity of the healed fracture altered under microgravity or unloaded conditions? [ISS 1 Moon 1 Mars 1]		
2b.	Are there site-specific differences, or differences in healing diaphyseal bone versus metaphyseal bone under microgravity or partial-gravity conditions? [ISS 3 Moon 3 Mars 3]		
2c.	Which cellular and biochemical changes in bone cell biology alter fracture healing under microgravity conditions? [ISS 3 Moon 3 Mars 3]		
2d.	Does the presence of microgravity-induced alteration in bone remodeling and/or osteoporosis affect fracture callus remodeling? [ISS 2 Moon 2 Mars 2]		
2e.	How does altered muscle biology contribute to altered fracture healing in microgravity? [ISS 4 Moon 4 Mars 4]		
2f.	Do biophysical modalities play a role in improving fracture healing in a microgravity environment? [ISS 2 Moon 2 Mars 2]		
2g.	Do biophysical modalities play a role in improving fracture healing in the presence of bone loss in a microgravity environment? [ISS 2 Moon 2 Mars 2]		
2h.	Are there anabolic agents, growth factors or cytokines that will speed fracture repair during microgravity, in combination with active bone loss due to unloading? [ISS 1 Moon 1 Mars 1]		
2i.	What technologies will be used to diagnose fractures of the axial and appendicular skeleton in a space environment? [ISS 1 Moon 1 Mars 1]		
2j.	Will different technologies be needed to treat either open or closed fractures in a space environment? [ISS 3 Moon 1 Mars 1]		
Related Risks	TBD		
Important References	Kirchen ME, O'Connor KM, Gruber HE, Sweeney JR, Fras IA, Stover SJ, Sarmiento A, Marshall GJ.. Effects of microgravity on bone healing in a rat fibular osteotomy model.Clin Orthop. 1995 Sep;(318):231-42.		
	Durnova GN, Burkovskaia TE, Vorotnikova EV, Kaplanskii AS, Arustamov OV. [The effect of weightlessness on fracture healing of rats flown on the biosatellite Cosmos-2044]. Kosm Biol Aviakosm Med. 1991 Sep-Oct;25(5):29-33. Russian.		

	Kaplansky AS, Durnova GN, Burkovskaya TE, Vorotnikova EV. The effect of microgravity on bone fracture healing in rats flown on Cosmos-2044. Physiologist. 1991 Feb;34(1 Suppl):S196-9.

Risk Title: Injury to Joints and Intervertebral Structures

Primary Risk Area	Bone		
Risk Number	3		
Risk Description	Injury to Joints and Intervertebral Structures		
Context/Risk Factors	Muscle and tendon loss of mechanical strength, work related impact on intervertebral disc structures, age, prior conditioning status, prior history of injuries.		
Specific current countermeasure(s) or mitigation(s)	Work injury avoidance patterns, Musculoskeletal Fitness, post-injury Rehabilitation.		
Specific projected countermeasure(s) or mitigation(s)	Coordinated muscle/tendon/ligament conditioning program.		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Yellow	Yellow	Yellow
Justification/Rationale for Risk	High likelihood/Moderate consequence.		
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
3a.	What is the cause of the back pain commonly experienced by crewmembers upon return to 1-G? [ISS 2 Moon 3 Mars 2]		
3b.	Is damage to joint structure or intervertebral discs incurred during or following hypogravity exposure? [ISS 2 Moon 3 Mars 1]		
3c.	What countermeasures will protect joint and intervertebral soft tissues from microgravity or partial Gravity-related damage? [ISS 2 Moon 2 Mars 1]		
3d.	What rehabilitative measures will hasten recovery of soft tissue damage in a partial Gravity environment or upon return to Earth's gravity? [ISS 2 Moon 2 Mars 1]		
Related Risks	TBD		
Important References	Hutton WC, Malko JA, Fajman WA. Lumbar disc volume measured by MRI: effects of bed rest, horizontal exercise, and vertical loading. Aviat Space Environ Med. 2003 Jan;74(1):73-8.		
	Foldes I, Kern M, Szilagyi T, Oganov VS. Histology and histochemistry of intervertebral discs of rats participated in space flight. Acta Biol Hung. 1996;47(1-4):145-56.		
	LeBlanc AD, Evans HJ, Schneider VS, Wendt RE 3rd, Hedrick TD. Changes in intervertebral disc cross-sectional area with bed rest and space flight. Spine. 1994 Apr 1;19(7):812-7.		
	Maynard JA. The effects of space flight on the composition of the intervertebral disc. Iowa Orthop J. 1994;14:125-33.		

	Pedrini-Mille A, Maynard JA, Durnova GN, Kaplansky AS, Pedrini VA, Chung CB, Fedler-Troester J. Effects of microgravity on the composition of the intervertebral disk. Appl Physiol. 1992 Aug;73(2 Suppl):26S-32S.
	Foldes I, Szilagyi T, Rapcsak M, Velkey V, Oganov VS. Changes of lumbar vertebrae after Cosmos-1887 space flight. Physiologist. 1991 Feb;34(1 Suppl):S57-8.
	Oganov VS, Cann C, Rakhmanov AS, Ternovoi SK. [Study of the musculoskeletal system of the spine in humans after long-term space flights by the method of computerized tomography] Kosm Biol Aviakosm Med. 1990 Jul-Aug;24(4):20-1. Russian.
	Stupakov GP, Mazurin YuV, Kazeikin VS, Moiseyev YB, Kaliakin VV. Destructive and adaptive processes in human vertebral column under altered gravitational potential. Physiologist. 1990 Feb;33(1 Suppl):S4-7. Review.

Risk Title: Renal Stone Formation

Primary Risk Area	Bone		
Risk Number	4		
Risk Description	Renal Stone Formation		
Context/Risk Factors	Individual propensity for urine calcium oxalate solubility patterns, Calcium loss from bone, fluid and mineral imbalance, altered renal function. Impact of extended environmental features regarding mineral/fluid alterations.		
Specific current countermeasure(s) or mitigation(s)	Maintained hydration, K Citrate.		
Specific projected countermeasure(s) or mitigation(s)	K Mg Citrate currently in testing in flight; urine solubility testing in flight; ultrasound of renal status to anticipate renal stone formation.		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Green	Green	Green
Justification/Rationale for Risk	TBD		
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
4a.	What diagnostic measures permit detection of renal calcification during extended- duration space flight? [ISS 4 Moon 1 Mars 1]		
4b.	What nutritional and/or pharmacological countermeasures adequately minimize risk of stone formation in-flight and upon return to 1G? [ISS 3 Moon 3 Mars 2]		
4c.	What is the time course of increased risk for renal stone formation abating upon return to 1G? [ISS 3 Moon 3 Mars 2]		
Related Risks	TBD		
Important References	Zerwekh JE. Nutrition and renal stone disease in space. Nutrition. 2002 Oct;18 (10):857-63. Review.		
	Whitson PA, Pietrzyk RA, Morukov BV, Sams CF. The risk of renal stone formation during and after long duration space flight. Nephron. 2001 Nov;89(3):264-70.		
	Whitson PA, Pietrzyk RA, Sams CF. Space flight and the risk of renal stones. J Gravit Physiol. 1999 Jul;6(1):P87-8.		

	Whitson PA, Pietrzyk RA, Sams CF. Urine volume and its effects on renal stone risk in astronauts. Aviat Space Environ Med. 2001 Apr;72(4):368-72.
	Whitson PA, Pietrzyk RA, Pak CY. Renal stone risk assessment during Space Shuttle flights. J Urol. 1997 Dec;158(6):2305-10.
	Whitson PA, Pietrzyk RA, Pak CY, Cintron NM. Alterations in renal stone risk factors after space flight. J Urol. 1993 Sep;150(3):803-7.
	Pak CY, Hill K, Cintron NM, Huntoon C. Assessing applicants to the NASA flight program for their renal stone-forming potential. Aviat Space Environ Med. 1989 Feb;60(2):157-61.

Risk Title: Occurrence of Serious Cardiovascular Dysrhythmias

Primary Risk Area	Cardiovascular Alterations		
Risk Number	5		
Risk description	Cardiac dysrhythmias pose a potentially lethal risk during long-duration space flight. Cardiac dysrhythmias may also cause hypotension and syncope. Cause is unknown.		
Context/Risk Factors	Possible risk factors include fluid and electrolyte imbalance, altered neural and hormonal regulation, diminished cardiac mass and cardiac remodeling, flight duration, pre-existing cardiovascular disease, gender, radiation exposure.		
Specific current countermeasure(s) or mitigation(s)	Resuscitation equipment including defibrillator on board		
Specific projected countermeasure(s) or mitigation(s)	• Electrical cardioversion (Equipment currently on board, efficacy not demonstrated in space environment) [CRL 1] • Pre-flight and in-flight testing of astronauts to assess altered susceptibility to dysrhythmias [CRL 7] • Nutritional countermeasure [CRL 2] • Pharmaceutical countermeasure [CRL 1]		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Yellow	Yellow	Yellow
Justification/Rationale for Risk	Serious cardiac rhythm disturbances including ventricular tachycardia have been observed on several occasions during space flight including a documented 14-beat run of ventricular tachycardia during a Mir mission. Recent flight and ground-based data demonstrate alterations in cardiac electrical activity, which may indicate altered cardiac electrical stability. If space flight increases the risk of serious cardiac dysrhythmias this could lead to syncope and/or death posing risk both to crewmembers and to the mission.		
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
5a.	Does space flight increase susceptibility to serious cardiac dysrhythmias? [ISS 1 Moon 1 Mars 1]		
5b.	What conditions of space flight (e.g., Microgravity, disruption of physiological rhythms, nutrition, environmental factors and radiation) may be responsible? [ISS 1 Moon 1 Mars 1]		
5c.	What mechanisms are involved? [ISS 1 Moon 1 Mars 1]		
5d.	Can risk of serious cardiac dysrhythmias be predicted for individual crewmembers? [ISS 1 Moon 1 Mars 1]		

5e.	What countermeasures may prevent or reduce the occurrence of serious cardiac dysrhythmias during long-term space flight? [ISS 1 Moon 1 Mars 1]
5f.	Can susceptibility to and occurrence of serious cardiac dysrhythmias be effectively diagnosed and treated during space flight? [ISS 1 Moon 1 Mars 1]
5g.	Which cardiovascular diseases are likely to be aggravated by space flight? [ISS 1 Moon 1 Mars 1]
5h.	What mechanisms are involved? [ISS 1 Moon 1 Mars 1]
5i.	What improved screening methods on the ground and in-flight might identify crewmembers with underlying cardiovascular disease which may be aggravated by space flight? [ISS 1 Moon 1 Mars 1]
5j.	What countermeasures may be effective in mitigating the risk? [ISS 1 Moon 1 Mars 1]
Related Risks	Diminished Cardiac Function, Clinical Capabilities
Important References	Charles JB, Bungo MW, Fortner GW. Cardiopulmonary Function. In: Nicogossian A, Huntoon C. Pool S. and (editors). Space Physiology and Medicine. 3rd ed. Philadelphia, PA: Lea & Febiger, 286-304, 1994.
	Hawkins WR, Zieglschmid JF. Clinical Aspects of Crew Health. In: Biomedical Results of Apollo (NASA SP-368). Johnston RS Dietlein LF, Berry CA, editors. Washington, DC: U.S. Government Printing Office, 43-81, 1975.
	Smith RF, Stanton K, Stoop D, Brown D, Januez W, King P. Vectorcardiographic Changes During Extended Space flight (M093): Observations at Rest and During Exercise. In: Biomedical Results of Skylab (NASA SP-377). Johnston RS and Dietlein LF, editors. Washington, DC: NASA 339-350, 1977.

Risk Title: Diminished Cardiac and Vascular Function

Primary Risk Area	Cardiovascular Alterations		
Risk Number	6		
Risk description	Short-duration space flight has been associated with a decrease in cardiac mass. Long-duration space flight may result in greater decrease in cardiac mass and additional alterations, which may diminish cardiac function and could be irreversible.		
Context/Risk Factors	Possible risk factors include flight duration, altered neural and hormonal regulation, gender.		
Specific current countermeasure(s) or mitigation(s)	Exercise		
Specific projected countermeasure(s) or mitigation(s)	Drugs that affect cardiac mass and function, artificial G exposure		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Yellow	Yellow	Yellow
Justification/Rationale for Risk	Ground based and flight data in humans and animals suggest that prolonged exposure to microgravity may lead to the reduction of cardiac mass and reduced cardiac function, although different studies have come to different conclusions in this regard. Carefully controlled studies from very long-duration to microgravity are required to definitively resolve this issue.		

Enabling Questions [Priority on scale of 1 (high) to 5 (low)]	
6a.	Does long-duration space flight lead to diminished cardiac function? [ISS 1 Moon 1 Mars 1]
6b.	What mechanisms are involved? [ISS 1 Moon 1 Mars 1]
6c.	Is the process reversible? [ISS 1 Moon 1 Mars 1]
6d.	What is the extent of reduction in cardiac function and/or mass associated with long-duration space flight? [ISS 1 Moon 1 Mars 1]
6e.	Can susceptibility to reduced cardiac function be predicted for individual crewmembers? [ISS 2 Moon 2 Mars 2]
6f.	What countermeasures may be effective in mitigating the risk? [ISS 1 Moon 1 Mars 1]
6g.	What are the physiological and environmental factors by which space flight decreases orthostatic tolerance? [ISS 1 Moon 1 Mars 1]
6h.	How does duration of space flight affect the severity and time course of orthostatic intolerance and what are the mechanisms? [ISS 2 Moon 2 Mars 2]
6i.	Is orthostatic intolerance likely to develop on the surface of Mars or the moon? [ISS 1 Moon 1 Mars 1]
6j.	Can space flight-induced orthostatic intolerance be predicted for individual crewmembers? [ISS 1 Moon 1 Mars 1]
6k.	What countermeasures can be developed to overcome or prevent orthostatic intolerance? [ISS 1 Moon 1 Mars 1]
6l.	What are the physiological and environmental factors by which space flight decreases aerobic exercise capacity? [ISS 1 Moon 1 Mars 1]
6m.	How does duration of space flight affect the severity of limitation of exercise capacity? [ISS 1 Moon 1 Mars 1]
6n.	Can aerobic exercise capacity limitation be predicted for individual crewmembers? [ISS 1 Moon 1 Mars 1]
6o.	What countermeasures can be developed to overcome aerobic exercise capacity limitation? [ISS 1 Moon 1 Mars 1]
6p.	What are the physiological and environmental factors by which space flight decreases orthostatic tolerance? [ISS 1 Moon 1 Mars 1]
6q.	Is orthostatic intolerance likely to develop on the surface of Mars or the moon? [ISS 1 Moon 1 Mars 1]
Related Risks	Clinical Capabilities, Impaired Cardiovascular Response to Exercise Stress
Important References	Blomqvist CG, Lane LD, Wright SJ, et al. Cardiovascular regulation at microgravity. In: *Scientific Results of the German Spacelab Mission D-2, Proceedings of Symposium at Norderney*, Sahm PR, Keller MH and Schiewe B, editors. Wissenschaftliche Projektfuhrung D2, RWTH Aachen, Care of DLR, Koln, pp. 688-690.

Risk Title: Define Acceptable Limits for Trace Contaminants in Air and Water

Primary Risk Area	Environmental Health		
Risk Number	7		
Risk description	There is a lack of information needed to set requirements for air and water quality, including sources of chemical microbial contaminants, identification of potential contaminants and the bases for setting acceptability limits for contaminants and combinations of contaminants.		
Context/Risk Factors	Remoteness: Crew health/susceptibility to degree of system closure		
Specific current countermeasure(s) or mitigation(s)	TBD		
Specific projected countermeasure(s) or mitigation(s)	TBD		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Green	Yellow	Red
Justification/Rationale for Risk	Excessive pollutant levels (including microbial contaminants) can jeopardize crew health and/or impair mission success. The severity and likelihood of any adverse effects depends on the specific pollutant and its measured concentration.		
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
7a.	What are the most likely sources of severe air pollution specific to ISS, lunar, and Mars missions and what methods can be used to control these sources over long periods of time? [ISS 1, Moon 1, Mars 1]		
7b.	What are the tolerance limits in terms of quantity and type of microorganisms in air, water, and food and on surfaces? [ISS 1, Moon 1, Mars 1]		
7c.	What approaches to setting exposure standards may be used when insufficient data are available to allow prediction of acceptable exposure levels? [ISS 1, Moon 1, Mars 1]		
7d.	What is the requirement for determining how rapidly acceptable air quality can be recovered after a severe pollution condition and what effect that recovery has on humidity condensate and the water recovery system? [ISS 1, Moon 1, Mars 1]		
7e.	Can automated real-time systems be used to monitor air quality for lunar and Mars missions and can the crew interpret results without ground support? [ISS N/A, Moon 1, Mars 1]		
7f.	How can traditional limited-time exposure and human toxicological data be used to predict acceptable values for inhalation exposures to single chemicals and/or to mixtures? [ISS 2, Moon 2, Mars 2]		
7g.	What impact do space flight-induced biological, physiological, and immunological changes have on the susceptibility of crewmembers to infectious agents and toxic substances in the air? [ISS 2, Moon 2, Mars 2]		
7h.	What are the effects of exposure to ultra fine and larger (respirable and non-respirable) particles (e.g., lunar dust) on crew health, safety and performance? [ISS N/A, Moon 2, Mars 2]		
7i.	What are the interactions of microbes, chemicals and plants in CELSS on air quality? [ISS N/A, Moon 2, Mars 2]		
7j.	To the extent that plants are critical to mission success, will the potential for phytotoxicity be adequately addressed in the evaluation of air quality? [ISS N/A, Moon N/A, Mars 2]		

7k.	Is there the potential for increased heterogeneity in terms of the distribution of air contaminants in the relatively larger lunar and Mars habitats? If so, what additional monitoring resources and/or strategies are necessary to protect crew health? [ISS N/A, Moon 2, Mars 2]
Related Risks	TBD
Important References	Pool, S.L. Ethylene Glycol Treatise. NASA/JSC Memorandum SD2-97-542, September 15, 1997.
	Nicogossian, A.E., et al. Crew Health in the Apollo-Soyuz Test Project Medical Report, NASA SP-411, 1977
	Huntoon, C.L., Toxicological Analysis of STS-40 Atmosphere, NASA/JSC Memorandum, SD4/01-93-251, July 6, 1991; Toxicological Analysis of STS-55 Atmosphere, NASA/JSC Memorandum SD4-93-251, July 6, 1993.
	James, J.T Toxicological Assessment of Air Samples Taken after the Oxygen-Generator Fire on Mir, NASA/JSC Memorandum SD2-97-513, April 10, 1997
	James, J.T., Toxicological Assessment of Air Contaminants during the Mir 19 Expedition, 1996

Risk Title: Immunodeficiency / Infection

Primary Risk Area	Immunology, Infection and Hematology
Risk Number	8
Risk description	It is likely that one of the central features of the effects of space flight is to suppress immune function, a newly designated form of secondary immunodeficiency disease (D.Y.M. Leung, Editor-in-Chief, J Allergy Clin Immunol 2001;107:21). Secondary immunodeficiency causes an unusual number of infections, with greater severity and duration. Moreover, secondary immunodeficiency leads to reactivation of latent virus infections with organisms that lay dormant until immune resistance is lowered and virus replication begins. This risk applies to all crewmembers.
Context/Risk Factors	Radiation, microgravity isolation, stress, microbial contamination, sleep deprivation, extreme environments, nutritional deprivation.
Specific current countermeasure(s) or mitigation(s)	Pre-flight Quarantine (Health Stabilization Program); onboard antibiotics, anti-viral agents, replacement intravenous immunoglobulins, routine immunizations, use of clean vehicles; air and water monitoring. Because of the shorter time exposure to space conditions on a lunar mission, the use of treatment countermeasures would be less. The long-duration and difficult living conditions of a Martian mission would stress the ability of countermeasures to remain effective (e.g., the development of bacteria, fungi, or viruses that are resistant to the anti-microbial agents brought on-board).

Specific projected countermeasure(s) or mitigation(s)	Pathogen-specific immunizations [CRL 6] Anti-viral agents [CRL 6] Monoclonal antibodies to viral, bacterial and fungal pathogens and inflammatory mediators, such as TNF-α; cytokines such as IFN-γ; bone marrow stem cells [CRL 6] Molecular detection systems for water and airborne pathogens [CRL 7] Detection systems for assessment of immune function [CRL 5] Because of the shorter duration of the lunar mission, the use of these countermeasures may be minimal. The Martian mission would be expected to produce the greatest need for these countermeasures, particularly monoclonal antibodies to pathogens and even autologous bone marrow stem cell transplants (technology to preserve these bone marrow stem cells in-flight for up to 3 years would need to be developed).		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Yellow	Yellow	Yellow
Justification/Rationale for Risk	The contributing risk factors of space flight collectively have a powerful effect upon the cells of the immune system: T cells, particularly $CD4^+$ (helper) T cells, B cells, NK cells, monocyte/ macrophages/dendritic cells and hematopoietic stem cells. Every component of immune resistance to infection is compromised under space flight conditions, particularly the ability of the central immune cell, the $CD4^+$ T cell. The experience of the lunar surface would create the same general risks as those of the ISS. The effects of microgravity would be slightly reduced and radiation would be greater than that on the ISS. The relatively short time of the lunar mission (10-44 days) would tend to reduce the risk of developing immunodeficiency and infection. The long-term exposure (>1 year) to deep-space radiation and prolonged exposure to microgravity (> 2 years), length of separation from humans, constant sleep deprivation and other conditions of space flight would offer the greatest challenge to the host immune system in protecting space travelers from the development of secondary immuno-deficiency and reactivated latent viral infections.		
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
8a.	What are the molecular and cellular mechanisms of innate and acquired immunity that become compromised with space flight conditions of radiation, microgravity, isolation, stress, microbial contamination, sleep deprivation, extreme environments and nutritional deficiency? [ISS 1, Moon 1, Mars 1]		
8b.	Is it possible to predict the summary effects of each component condition and duration (1-year ISS, 30-day lunar, 18-month Mars) of space flight that compromises the immune system? [ISS 1, Moon 1, Mars 1]		
8c.	What types of infections are likely to occur in astronauts exposed to space flight conditions of different missions and durations? [ISS 1, Moon 1, Mars 1]		
8d.	Are there detection systems that can assess surrogate markers of immune function so that therapeutic interventions could be planned/during space flight? [ISS 2, Moon 2, Mars 2]		
8e.	Will it be possible to use immune protection measures to prevent infection aboard spaceships and to use antimicrobial therapies and immunological treatments to cure infections and prevent their complications? [ISS 2, Moon 2, Mars 2]		

8f.	Will nutritional supplements be able to boost immune responses in space flight to counteract the infectious complication of compromised immune function? [ISS 1, Moon 1, Mars 1]
Related Risks	Radiation Effects, Environmental Health, Food and Nutrition, Sleep and Circadian Rhythm Problems, Human Behavior and Performance, Clinical Capabilities, Multisystem Alterations
Important References	Aviles H, Belay T, Fountain K, Vance M, Sonnenfeld G. Increased susceptibility to Pseudomonas aeruginosa infection hindlimb unloading conditions. J Appl Physiol 95:73-80, 2003.
	Belay T, Sonnenfeld G. Differential effects of catecholamines on in vitro growth of pathogenic bacteria. Life Sci 71:447-456, 2002.
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Risk Title: Virus-Induced Lymphomas and Leukemia

Primary Risk Area	Immunology, Infection and Hematology		
Risk Number	9		
Risk description	This risk is unique and takes place in humans who are immunosuppressed and develop latent virus reactivation. At least 2% of organ and bone marrow transplanted patients experience Epstein-Barr virus reactivation, leading to B-cell lymphomas. Host genetic factors are known to influence susceptibility to lymphoid malignancies. Similarly, severely compromised patients with AIDS whose $CD4^+$ T-cell count falls below 50 cells/µl experience human herpesvirus-8-induced Kaposi's sarcoma. Latent human T-cell leukemia virus (HTLV)-1 and HLTV-2 infection in immunosuppressed hosts can lead to T-cell leukemias. Since the astronauts all carry many of these latent viruses in their bodies because of universal exposure, it is likely that if their immune resistance is lowered to a critical level, they too will be subject to B-cell lymphomas and T-cell leukemias. The risk applies to all crewmembers.		
Context/Risk Factors	Immunodeficiency due to space flight conditions, latent virus reactivation and host genetics.		
Specific current countermeasure(s) or mitigation(s)	Monitor exposure to radiation and other environmental factors. Radiation shielding. Ongoing health status monitoring. Monoclonal anti-B cell (tumor) antibody (Rituximab); cytotoxic anti-EBV T cells; radiation shielding. Use of monoclonal anti-B cell tumor antibodies and cytotoxic anti-EBV T cells may not be necessary on the short Moon mission, but they may be necessary after return to Earth. Technology needs to be developed to preserve autologous cytotoxic anti-EBV T cells on board the spacecraft in the Martian mission. The other countermeasures could presently be delivered in deep-space.		
Specific projected countermeasure(s) or mitigation(s)	Specific antiviral drugs [CRL 7] Fusion proteins to block virus reinfection [CRL 6] Autologous stem cell transplants [CRL 2] Use of countermeasures may not be needed on short voyages to the Moon, but in later years if tumors develop. Need to develop radiation-proof container for autologous stem cell transplants. The other countermeasures can be delivered in deep-space.		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Yellow	Green	Yellow

Justification/Rationale for Risk	Due to severe immunosuppression caused by several space flight conditions (radiation, microgravity, isolation, stress, microbial contamination, sleep deprivation, extreme environments, nutritional deprivation), latent viruses (e.g., Epstein-Barr virus, polyomaviruses) become active and favor the selection of escape mutant lymphoid cells, which lack replication controls. These clones of lymphoid cells become oligoclonal and finally monoclonal and grow without inhibition. The nests of these clones grow into tumors that disrupt normal tissue and architecture, sap the energy of normal cells and kill the host in a short period of time. The relatively short exposure of astronauts to space flight conditions in the lunar mission may not yield the final development of malignancy. However, Alan Shepard, the fifth man to step on the moon (and one of 12 to do so) surface died of T-cell leukemia. It is possible that the premalignancy is triggered in the appropriate genetic host years before oncogenic transformation occurs. Publication of the long-term health consequences of NASA's space pioneers will prove an important source of clinical evidence. The length and severity of space flight conditions of the Martian Mission are expected to pose the most dangerous risk for the development of immune cell-mediated leukemias and lymphomas. Animal model studies are the only means, at present, by which to assess the risk of virus-induced tumors in an immunosuppressed host.
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]	
9a.	What are the molecular and genetic mechanisms of host defense cells and latent virus genomes that become altered with immunosuppression produced by space flight conditions and latent virus reactivation, leading to lymphoid tumor production? [ISS 1, Moon 1, Mars 1]
9b.	Will the degree of immune compromise, latent virus reactivation and lymphoid malignancy vary with the space mission and its duration (1-year ISS, 30-day lunar, 18-month Mars)? [ISS 1, Moon 1, Mars 1]
9c.	Is it possible to predict the summary effects of each component condition and duration of space flight that produce lymphoid malignancies? [ISS 1, Moon 1, Mars 1]
9d.	What are the types of lymphoid malignancies (lymphomas, leukemias) that are likely to occur in immunosuppressed astronauts with reactivated latent viral infections? [ISS 1, Moon 1, Mars 1]
9e.	Are there virus quantitation assays to predict those astronauts who will develop malignancies and who would benefit from immune intervention? [ISS 2, Moon 2, Mars 2]
9f.	Will it be possible to use anti-viral and anti-tumor agents aboard spaceships to reduce viral burden and abort forbidden clone development? [ISS 2, Moon 2, Mars 2]
9g.	Will it be possible to develop nutritional supplements to augment anti-viral and anti-tumor therapy? [ISS 2, Moon 2, Mars 2]
9h.	Will it be possible to restore immunity in a severely immunocompromised astronaut with autologous stem cell transplants? [ISS 3, Moon 3, Mars 3]
Related Risks	Environmental Health, Radiation Effects, Clinical Capabilities, Food and Nutrition, Multi-systems Alterations
Important References	Chinen J, Shearer WT. Immunosuppression induced by therapeutic agents and by environmental conditions. In Stiehm ER, ed. Immunologic disorders in infants and children, 5th Edition. Philadelphia: WB Saunders, in press, 2004.
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	Pecaut MJ, Gridley DS, Smith AL, Nelson GA, Dose and dose rate effects of whole-body proton-irradiation on lymphocyte blastogenesis and hematological variables: part II. Immunol Lett 80:67-73, 2002.
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Risk Title: Anemia, Blood Replacement & Marrow Failure

Primary Risk Area	Immunology, Infection, & Hematology		
Risk Number	10		
Risk description	Anemia, blood replacement and marrow failure (human work performance failure due to anemia), resulting in compromised mission objectives.		
Context/Risk Factors	Age, gender, baseline, nutrition, marrow stores, trauma – loss & destruction, decreased production, need during surgery		
Specific current countermeasure(s) or mitigations(s)	Nutrition, pharmaceutical, blood replacement, hormonal & stem cell therapy		
Specific projected countermeasure(s) or mitigation(s)	TBD		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Green	Yellow	Yellow
Justification/Rationale for Risk	TBD		
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
10a.	What are the methods for space based therapy for blood replacement? What new technologies are needed for blood replacement in space? [ISS 3, Moon 2, Mars 1]		
10b.	What are the nutritional requirements for adequate red cell production in microgravity? What are the contributory factors and how do they inter-relate in the development of space anemia (radiation, unloading, nutrition, fluid shift, changes in sex hormones, etc.)? [ISS 2, Moon 2, Mars 2]		
10c.	How can aplastic anemia be treated during space missions? [ISS 5, Moon 5, Mars 3]		
Related Risks	TBD		
Important References	TBD		

Risk Title: Altered Host-Microbial Interactions

Primary Risk Area	Immunology, Infection and Hematology		
Risk Number	11		
Risk description	Altered Host – Microbial Interactions. Humans exist in a delicate balance with a world of microorganisms and over eons of time have adapted to the potential toxic nature of these microbes. When astronauts leave Earth's protective environment, space flight conditions are very likely to disturb that balance between host and microbe, leading to infection. [Insubstantial?] With radiation in space, there is the possibility that organisms never seen by the human immune system could arise and kill the host. There are parallel examples of this when microorganisms are first spread to humans, the host response is not fast enough for protection and death is the consequence (e.g., Ebola virus and SARS virus). This risk applies to all crewmembers.		
Context/Risk Factors	Radiation, microgravity, isolation, stress, microbial contamination, extreme environments, sleep deprivation, nutritional deprivation.		
Specific current countermeasure(s) or mitigation(s)	In-flight environmental monitoring and bioburden reduction procedures.		
Specific projected countermeasure(s) or mitigation(s)	In-flight antibiotic susceptibility testing capability [CRL 6] Pre-flight screening [CRL 7] Routine In-flight microbial identification/monitoring capability [CRL 6] Comprehensive microbial identification technology based on mass spectrometry and/or hybridization [CRL 5]		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Green	Green	Yellow
Justification/Rationale for Risk	Changes in microflora; novel microbial ecosystems; genetic changes/mutations of microorganisms; alterations in host microbe interaction; alterations in host susceptibility. The short-duration of the lunar mission might not provide sufficient time for significant alterations in the host: microbe relationship. The long-duration and severe nature of space flight conditions on a Mars mission would favor the alterations in the host: microbe relationship. Possibly, evolution of a supermicrobe that overpowers the human immune response would be favored.		
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
11a.	What diagnostic and environmental monitoring laboratory technologies need to be developed for the detection and diagnosis of infectious disease in space? [ISS 1, Moon 1, Mars 1]		
11b.	Does the spacecraft environment exert a selective pressure on environmental microorganisms that presents the crew with increased health risks (e.g., Helicobacter and ulcers)? [ISS 1, Moon 1, Mars 1]		
11c.	Does space flight alter microbial growth rates, mutation rates, or pathogenicity? [ISS 1, Moon 1, Mars 1]		
11d.	Does space flight alter the exchange of genetic material between microorganisms? [ISS 1, Moon 1, Mars 1]		
11e.	Does space flight alter host-microbe balance? [ISS 1, Moon 1, Mars 1]		

11f.	Can molecular and genetic testing of pathogenetic microbial organisms during space flight be accomplished on a real-time basis to prevent development of infections in astronauts? [ISS 2, Moon 2, Mars 2]
11g.	Do microorganisms associated with biological life support systems or biological waste treatment systems enter the general spacecraft environment with consequent increase in health risks? [ISS 1, Moon 1, Mars 1]
Related Risks	Environmental Health (4), Multisystem (Cross Risk) Alterations (12), Clinical Capabilities (11)
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Risk Title: Allergies and Autoimmune Diseases

Primary Risk Area	Immunology, Infection and Hematology		
Risk Number	12		
Risk description	Allergies and Autoimmune Diseases. Genetic inheritance and environmental insults are the two factors that trigger the development of allergic and autoimmune diseases. Failure of immunologic tolerance due to malfunction of regulatory immune mechanisms brings on immune-mediated diseases in life. Space flight conditions have been shown to upset immune regulation and produce immunologic disease in experimental systems. This risk applies to all crewmembers.		
Context/Risk Factors	Radiation, microgravity, isolation, stress, microbial contamination, sleep deprivation, extreme environments, nutritional deprivation.		
Specific current countermeasure(s) or mitigation(s)	Toxicological/Environmental/Microbiological standards for spacecraft atmosphere.		
Specific projected countermeasure(s) or mitigation(s)	Monoclonal anti-IgE antibody [CRL 7] Antigen peptide immunotherapy [CRL 6] Dendritic cell-antigen vaccines [CRL 6] Th1 immunostimulants (e.g., CpG) [CRL 7] Monoclonal antibody to $CD52^{+}$ cells [CRL 6] TNF-α, $C3^{+}$ T cells, $CD19^{+}/20^{+}$ B cells; soluble receptors (7) for TNF-α, IL-1, IL-2. Use of these countermeasures may not be needed in the lunar mission but may be needed later in life. These countermeasures must be ready for use in a Mars mission.		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Green	Green	Yellow
Justification/Rationale for Risk	In contrast to immunodeficiency where a lowered immune response looks to a predilection for opportunistic infection and malignancy, a heightened immune response leads to allergic and autoimmune diseases, which are part of the spectrum of hypersensitivity reactions mediated by IgE (Type I), antibody-cell receptor interactions (Type II), immune complexes (Type III) and T-cell mediated diseased (Type IV). Central to all of these paradoxical over-reactions of the immune system is the immunoregulatory T cell ($CD4^{+}DC25^{+}$)" Space flight conditions have the potential to affect this cell and other immunoregulatory cells that networks to produce all of our types of hypersensitivity: Allergy (Type I) and Autoimmune Diseases (Types II, III, IV). Although the lunar mission is short in duration, there may be sufficient loss of fine control of immune tolerance to produce immune diseases later in life. It is very likely that severe allergies and autoimmune diseases will result from a Martian mission, unless specific counter-measures are developed. The length and severity human exposure to environmental insults will most likely result in allergic and immunologic diseases.		
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
12a.	What are the molecular and genetic mechanisms of loss of immunoregulation and immune tolerance in that occur with the exposure to the space flight conditions of radiation, microgravity, isolation, stress, microbial contamination, sleep deprivation, extreme environments and nutritional deficiency? [ISS 1, Moon 1, Mars 1]		

12b.	Is it possible to predict the summary effects of each component condition on duration of space flight (1-year ISS, 30-day, 18-month Martian) that leads to immune dysregulation and loss of immune tolerance? [ISS 1, Moon 1, Mars 1]
12c.	What are the allergies and autoimmune diseases that are likely to occur in astronauts exposed to space flight conditions of different missions and durations? [ISS 1, Moon 1, Mars 1]
12d.	Are there detection systems that can detect the first alterations in immune regulatory networks so that therapeutic intervention could be planned? [ISS 2, Moon 2, Mars 2]
12e.	Will it be possible to use new immune regulatory agents to prevent immune imbalance with the expressions of allergies and autoimmune conditions? [ISS 2, Moon 2, Mars 2]
12f.	Will it be possible to use nutritional supplements to boost the immunoregulatory agents used therapeutically? [ISS 2, Moon 2, Mars 2]
Related Risks	Environmental Health, Radiation Effects, Clinical Capabilities, Food and Nutrition
Important References	Chitnis T, Khoory SJ. Role of costimulatory pathways in the pathogenesis of multiple sclerosis and experimental autoimmune encephalitis. J Allergy Clin Immunol 112:837-849, 2003.
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	Nelson RP Jr, Ballow M. Immunomodulation and immunotherapy: drugs, cytokines, cytokine receptors and antibodies. J Allergy Clin Immunol 11:S720-S732, 2003.
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Risk Title: Skeletal Muscle Atrophy Resulting in Reduced Strength and Endurance

Primary Risk Area	Skeletal Muscle Atrophy		
Risk Number	13		
Risk description	Given that the unloading of the musculoskeletal system during space flight is associated with muscle fiber atrophy and a decrease in muscle size, this deficiency could impact other systems (e.g., cardiovascular, bone) and result in an inability or reduced ability/fidelity in performing mission-directed physical activities.		
Context/Risk Factors	Muscle atrophy is the result of sarcopenia or net protein catabolism associated with skeletal muscle unloading and this alteration likely increases compliance of the muscle vascular bed which could impair venous return (i.e., muscle pump) and contribute to orthostatic intolerance upon re-exposure to a gravitational environment and accelerate bone loss due to reductions in muscle tone and the force generating capacity of the muscle and the corresponding reduction of force at the tendon/bone interface.		
Specific current countermeasure(s) or mitigation(s)	Moderate resistance exercise, treadmill, cycle ergometer. (TRL-6)		
Specific projected countermeasure(s) or mitigation(s)	Artificial gravity (e.g., centrifuge with exercise capabilities). (TRL-3)		
	New programs of heavy resistance exercise (e.g., expanded exercise and loading capabilities). (TRL-6)		
	Pharmacological interventions. (TRL-2)		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Green	Green	Yellow
Justification/Rationale for Risk	Growing database demonstrating that skeletal muscles, particularly postural muscles of the lower limb, undergo atrophy and undergo structural and metabolic alterations during space flight.		
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
13a.	What is the time course of skeletal muscle atrophy during an ISS, lunar, and Mars mission? [ISS 1, Moon 1, Mars 1]		
13b.	Does muscle atrophy of the lower extremity muscles contribute to orthostatic hypotension due to deficiencies in the muscle pump? [ISS 1, Moon 1, Mars 1]		
13c.	Does skeletal muscle atrophy contribute to the accelerated rate of bone loss in the central and peripheral skeleton because of reduced forces at the tendon insertion sites during long-duration space missions? [ISS 1, Moon 2, Mars 1]		
13d.	What hardware and/or technologies are currently available, or need to be developed for an ISS, lunar, or Mars mission in order to simulate the type of musculoskeletal loading experienced here on Earth to preserve muscle structure and function? [ISS 3, Moon 3, Mars 3]		
13e.	What are the effects of skeletal muscle atrophy on whole body metabolism (e.g., insulin and glucose tolerance)? [ISS 1, Moon 3, Mars 1]		
13f.	Are the deleterious changes that occur in skeletal muscle (atrophy, alterations in contractile phenotype, etc.) during long-duration space flight missions completely reversible upon return to Earth? [ISS 3, Moon 3, Mars 3]		
13g.	What combination of exercise and/or hormonal/pharmacological, nutritional and micronutrient supplements are effective in preserving muscle structure and function during ISS, lunar, and Mars missions? [ISS 1, Moon 1, Mars 1]		
13h.	What are the appropriate prescription modalities (exercise regimens, artificial gravity, etc.) and the compliance factors needed during an ISS, lunar, and Mars mission to minimize losses in muscle mass and strength? [ISS 1, Moon 1, Mars 1]		

13i.	What are the effective resistance exercise modalities (contraction modes) and exercise prescriptions (frequency, intensity, duration) needed to maintain skeletal muscle structure and function during an ISS, lunar, and Mars mission? [ISS 1, Moon 1, Mars 1]
13j.	What are the appropriate prescription modalities (exercise regimens, physical therapy, etc.) and the compliance factors needed to facilitate skeletal muscle rehabilitation in crewmembers returning from microgravity, 1/3-gravity, or 1/6-gravity? [ISS 1, Moon 1, Mars 1]
13k.	What cellular processes/signaling pathways in skeletal muscle can be identified and targeted (pharmacological, gene therapy, hormones, etc.) to prevent or attenuate fiber atrophy during ISS, lunar, or Mars missions? [ISS 3, Moon 3, Mars 3]
13l.	What practical diagnostic tools (e.g., biochemical markers, ultrasound) can be used during ISS, lunar, and Mars missions to monitor and quantify changes in muscle structure and function? [ISS 3, Moon 3, Mars 3]
13m.	Is the capacity of skeletal muscle to grow or regenerate (satellite cells) compromised during or after a mission because of conditions (e.g., radiation exposure, reduced muscle tension) associated with an ISS, lunar, and Mars mission? [ISS 3, Moon 2, Mars 1]
13n.	What are the temporal relationships between the changes in structure and function of the tendon, muscle and muscle-tendon interface? [ISS 2, Moon 2, Mars 2]
13o.	How do the deficits in skeletal muscle strength associated with long-duration space flight affect the structural/functional properties of the sensory system and motor nerves? [ISS 1, Moon 1, Mars 1]
13p.	Can those resistance exercise paradigms and other activity modalities aimed at counteracting atrophy processes maintain those deficits in muscle strength that appear to occur independent of the atrophy process? [ISS 1, Moon 1, Mars 1]
13q.	What are the bioenergetic, metabolic and substrate-processing factors that contribute to the reductions in skeletal muscle endurance associated with muscle atrophy? [ISS 1, Moon 1, Mars 1]
13r.	Can endurance exercise activities that normally enhance skeletal muscle endurance under weight bearing conditions effectively maintain this property in atrophying muscle when they are performed in microgravity environments? [ISS 2, Moon 2, Mars 2]
13s.	How does the atrophy process affect the structural and functional properties of connective tissue (tendons), the fiber-tendon interface and the tendon-bone interface? [ISS 2, Moon 2, Mars 2]
13t.	Do resistance-training paradigms that counteract muscle atrophy processes improve the structure-function properties of connective tissue systems? (countermeasure) [ISS 2, Moon 2, Mars 2]
13u.	Do strength-training programs that minimize atrophy processes and strengthen muscle tendon properties that are performed in states of unloading prevent injury from occurring during the return to normal weight bearing states? [ISS 1, Moon 1, Mars 1]
13v.	What are the appropriate prescription modalities (exercise regimens, physical therapy, etc.) and the compliance factors needed to facilitate skeletal muscle rehabilitation in crewmembers returning from the ISS, Moon, or Mars to Earth gravity? [ISS 1, Moon 1, Mars 1]
13w.	What combination of exercise and/or hormonal/pharmacological, nutritional and micronutrient supplements are effective in preserving muscle structure and function during missions to the ISS, Moon, and Mars? [ISS 2, Moon 2, Mars 2]
13x.	What hardware and/or technologies are currently available, or need to be developed for an ISS, lunar, and Mars mission in order to simulate the type of musculoskeletal loading experienced here on Earth to preserve muscle structure and function? [ISS TBD, Moon TBD, Mars TBD]
13y.	To what extent should transcutaneous electrical stimulation be used as a countermeasure for preserving skeletal muscle structure and function during space flight? [ISS TBD, Moon TBD, Mars TBD]
13z.	If a muscle injury occurs during a space flight mission, what criteria will be used to determine when it is safe for a crewmember to resume exercise? [ISS TBD, Moon TBD, Mars TBD]
13aa.	Are there assistance devices/technologies that can compensate for losses in muscle mass and strength and prevent injury during a space mission? [ISS TBD, Moon TBD, Mars TBD]

13bb.	What are the effects of skeletal muscle atrophy on whole body metabolism? [ISS TBD, Moon TBD, Mars TBD]
13cc.	What are the effects of muscle atrophy on thermoregulation? [ISS TBD, Moon TBD, Mars TBD]
Related Risks	Cardiovascular, bone loss, nutrition
Important References	Adams GR, Caiozzo VJ, Baldwin KM. Skeletal muscle unweighting: space flight and ground-based models. J Appl Physiol. 95:2185-220, 2003.
	di Prampero PE, Narici MV. Muscles in microgravity: from fibers to human motion. J Biomech.;36(3):403-12, 2003.
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	McCall GE, Goulet C, Boorman GI, Roy RR, Edgerton VR. Flexor bias of joint position in humans during space flight. Exp Brain Res. 152: 87-94. 2003.
	Narici M, Kayser B, Barattini P, Cerretelli P. Changes in electrically evoked skeletal muscle contractions during 17-day space flight and bed rest. Int. J. Sports Medicine 18: S290-S292, 1997.
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	Antonutto G, Capelli C, Girardis M, Zamparo P, di Prampero PE. Effects of microgravity on maximal power of lower limbs during very short efforts in humans. J Appl Physiol. 86: 85-92, 1999.
	LeBlanc, A, Lin C, Shackelford L, Sinitsyn V, Evans H, Belichenko O, Schenkman B, Kozlovskaya I, Oganov, V, Bakulin, A, Hedrick T and Feeback, D. Muscle volume, MRI relaxation times (T2) and body composition after space flight. J. Appl. Physiol. 89: 2158-2164, 2000.
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	Zhou MY, Klitgaard H, Saltin B, Roy RR, Edgerton VR, Gollnick PD. Myosin heavy chain isoforms of human muscle after short-term space flight. J Appl Physiol. May; 78(5):1740-4, 1995.
	Convertino VA, Doerr DF, Stein SL. Changes in size and compliance of the calf after 30-days of simulated microgravity. J Appl Physiol. Mar; 66(3):1509-12, 1989.

Risk Title: Increased Susceptibility to Muscle Damage

Primary Risk Area	Increased Susceptibility to Muscle Damage		
Risk Number	14		
Risk description	The unloading of the musculoskeletal system during space flight is associated with muscle fiber atrophy, changes in structural proteins and remodeling of associated connective tissues (e.g., intramuscular, muscle tendon interface, etc.), a deficiency that could make skeletal muscle more susceptible to damage when loaded.		
Context/Risk Factors	Given the reductions in skeletal muscle size, strength and endurance that result from space flight exposure, there is a greater likelihood of sustaining muscle and/or connective tissue damage and soreness that could result in an inability or reduced ability/fidelity in performing mission-directed physical activities.		
Specific current countermeasure(s) or mitigation(s)	Moderate resistance exercise, treadmill, cycle ergometer. (TRL-6)		
Specific projected countermeasure(s) or mitigation(s)	New programs of heavy resistance exercise (e.g., expanded exercise and loading capabilities). (TRL-6)		
	Artificial gravity (e.g., centrifuge with exercise capabilities). (TRL-3)		
	Pharmacological interventions. (TRL-2)		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Green	Green	Yellow
Justification/Rationale for Risk	Growing database based on space flight and ground based studies demonstrating that muscle atrophy processes are associated with changes in structural proteins and connective tissues, which could impair performance of various activities during and after ISS, lunar, or Mars missions.		
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
14a.	If a muscle injury occurs during an ISS, lunar or Mars mission, what criteria can be used to determine when it is safe for a crewmember to resume exercise or perform dynamic activities associated with the mission (e.g., EVA/exploration)? [ISS 1, Moon 1, Mars 1]		
14b.	Do strength-training programs that minimize atrophy processes and strengthen muscle tendon properties that are performed in states of unloading prevent injury from occurring during a mission and upon return to weight bearing states (e.g., 1-G)? [ISS 1, Moon 1, Mars 1]		
14c.	Do resistance-training paradigms that counteract muscle atrophy processes improve the structure-function properties of connective tissue systems? [ISS 2, Moon 2, Mars 2]		
14d.	How does the atrophy processes affect the structural and functional properties of connective tissue (tendons), the fiber-tendon interface and the tendon-bone interface? [ISS 3, Moon 3, Mars 3]		
14e.	Are the deleterious changes that occur in skeletal muscle (atrophy, alterations in contractile phenotype, etc.) during long-duration space flight missions completely reversible upon return to Earth? [ISS 3, Moon 3, Mars 3]		
14f.	Do the deficits in skeletal muscle associated with long-duration space flight affect the structural/functional properties of the sensory system and motor nerves (e.g., motor unit recruitment strategies within a muscle, altered muscle recruitment strategies for a given joint)? [ISS 1, Moon 1, Mars 1]		

14g.	What are the appropriate ground-based space flight analog environments that can be used as test beds for evaluating neurological adaptation time constants, adverse operational implications, countermeasures and impacts of adaptation on other anatomical and physiological systems? [ISS 1, Moon 1, Mars 1]
Related Risks	Bone Loss
Important References	Adams GR, Caiozzo VJ, Baldwin KM. Skeletal muscle unweighting: space flight and ground-based models. J Appl Physiol. 95:2185-220, 2003.
	di Prampero PE, Narici MV. Muscles in microgravity: from fibers to human motion. J Biomech.;36(3):403-12, 2003.
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	Baldwin KM, Edgerton VR, Roy RR. Muscle loss in space: physiological consequences. Encyclopedia of Space Sciences and Technology. Vol. 2; H. Mark, M. Salkin and A. Yousef (eds). John Wiley & Sons, Inc. Hoboken NJ, 2003, pp. 149-166.
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	Antonutto G, Capelli C, Girardis M, Zamparo P, di Prampero PE. Effects of microgravity on maximal power of lower limbs during very short efforts in humans. J Appl Physiol. 86: 85-92, 1999.
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	Edgerton VR, Zhou MY, Ohira Y, Klitgaard H, Jiang B, Bell G, Harris B, Saltin B, Gollnick PD, Roy RR, et al. Human fiber size and enzymatic properties after 5 and 11 days of space flight. J Appl Physiol. May; 78(5):1733-9, 1995
	Zhou MY, Klitgaard H, Saltin B, Roy RR, Edgerton VR, Gollnick PD. Myosin heavy chain isoforms of human muscle after short-term space flight. J Appl Physiol. May; 78(5):1740-4, 1995.
	Tidball JG, Quan DM. Reduction in myotendinous junction surface area of rats subjected to 4-day space flight. J Appl Physiol. Jul; 73(1):59-64, 1992 .

Risk Title: Vertigo, Spatial Disorientation and Perceptual Illusions

Primary Risk Area	**Neurovestibular Adaptation**		
Risk Number	15		
Risk description	When astronauts transition between gravitational environments, head movements and/or vehicle maneuvering can cause spatial disorientation, perceptual illusions, and/or vertigo. Should any of these occur in flight deck crewmembers during critical entry or landing phases they could lead to loss of vehicle. In-flight spatial disorientation can cause operational difficulties during docking and remote manipulation of payloads that can (and has) caused dangerous collisions, while in-flight frame-of-reference illusions, direction vertigo, or navigation problems could cause reaching errors, spatial memory failures, difficulty locating emergency egress routes, and/or fear of falling during EVA (height vertigo). While rotational AG (AG) has great potential as a bone, muscle, cardiovascular, and vestibular countermeasure, head movements out of the plane of rotation will produce illusory spinning sensations about an axis orthogonal to the head motion, which may lead to spatial disorientation.		
Context/Risk Factors	Landing: 1) Manual or supervisory control of vehicle by crewmember during critical phase of flight. 2) 0-G exposure duration. (Vertigo is an aftereffect of neurovestibular adaptation to 0-G, which may require several weeks.) 3) Non-zero gravitational level. 4) Pilot head movements, especially large or rapid ones. (Head movement contingent vertigo reported in early phases of entry. Orbiter crews routinely make slow practice head movements during entry to initiate re-adaptation). 5) Vehicle maneuvers (e.g. deceleration on inner glide slope; flare). 6) Turbulence or wind shear in approach area. 7) Poor visual reference to runway environment. (e.g., approaches at night or with low ceilings or poor visibility or to unfamiliar runway). In-Flight: 1) Ambiguous visual orientation cues (interior architectural symmetries, rack orientation and labeling, EVA visual cues). 2) Inconsistent visual verticals (within and between modules). 3) Physical orientation of 1-G training modules. 4) Teleoperations requiring user to cognitively integrate several different views of a work area, or transform commands to a different reference frame. 4) Individual ability differences (mental rotation, perspective taking, and sense of direction).		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Yellow	Yellow	Yellow
Specific current countermeasure(s) or mitigation(s)	[ISS]: Landing: 1) Re-adaptation head movements during entry. No formal procedure exists. Efficacy is unknown. 2) Restrictions on night and low ceiling/visibility approaches. Visual approach aids and runway lighting. 3) Shuttle pilot's 0-G exposure currently limited to 2-3 weeks. 4) CDRs are space flight veterans. CDR flies approach, PLT assists. Previous flight experience may help pilots cope with vertigo. In-Flight: 1) Pre-flight training in 1-G modules and neutral buoyancy 2) Pre-flight EVA training using virtual reality techniques. 3) Luminous exit placards, and module surface labels. [Moon and Mars]: None		

Specific projected countermeasure(s) or mitigation(s)	[ISS]: Landing: 1) Correlate shuttle approach flight technical error, vehicle accelerations, head movements, display legibility, post-flight visual acuity, gaze stability, OTTR, and G-excess illusions. (CRL0) 2) Determine efficacy of re-adaptation head movements during entry. (CRL2) 3) Redesign cockpit procedures and displays (e.g. flight director) to minimize head movements and accelerations, and to improve legibility during vertigo. (CRL2) 4) Implement shuttle auto-land capability at landing sites. (TRL7) Evaluate landing vertigo effect on pilots supervisory control capability. (CRL0) 5) Evaluate pre-flight or in-flight neurovestibular g-context-specific pre-adaptation techniques (e.g. short radius artificial gravity) and in-flight landing rehearsal simulators. (CRL2) 1) Pre-flight visual orientation training for IVA activities using VR techniques. (TRL/CRL 2-5) 2) Quantitative metrics for visual symmetry and polarity cues. (CRL4) 3) Improved standards for workstation and spacecraft interior architecture. (CRL4) 4) Validated spatial ability tests to predict and improve individual performance. (CRL 2) 5) Improved teleoperator displays. (CRL 2) [Moon and Mars]: Landing: 1) Auto-land capability on lunar or Mars landing and return vehicles. 2) Pre-flight or in-flight g- specific pre-adaptation techniques, (e.g. artificial gravity) (CRL2, TRL1)

Justification/Rationale for Risk	[ISS]: Problem has been with us throughout Shuttle program (e.g. perhaps as early as STS-3), and became recognized after multi-week shuttle missions in late 90s (cf. McCluskey, et al 2001). Currently constrains time on orbit of shuttle pilots, and night and low visibility approaches. Shuttle auto-land capability has not been operationally verified, and contingency landing sites do not have required microwave landing system. Skylab and Shuttle crews described almost universal incidence of occasional in-flight spatial disorientation and frame-of-reference illusions. Mir and ISS crews report susceptibility continues throughout long missions, and are exacerbated by complex 3D station architectures, inconsistent interior visual verticals, and perhaps by physical orientation of their ground trainers. Shuttle crews visiting Mir and ISS occasionally became lost, a concern in case emergency egress was required. EVA crewmembers occasionally report disorientation and disabling fear of falling to Earth. Reference frame integration problems have been noted by Shuttle and ISS teleoperators, and contributed to Mir-Progress collision, and complicated several other emergencies NASA Man System Integration Standard 3000 required locally consistent cue orientation and lighting, but did not address consistency between modules or work areas. However ISS (SSP5005) deleted many MSIS requirements. ISS modules have symmetric cross section and dual visual verticals. [Moon]: Some degree of manual control and maneuvering will be required for landing at unprepared lunar landing sites. Effects on crew capability of 7 day 0-G transits and 30 day adaptation to lunar 1/6 g, and are currently unknown. Apollo mission durations were less than 15 days. Crews' 1/6 g exposure on lunar surface was limited to 75 hours. No vertigo reported during lunar landing or EVA. Lunar Module did not have auto-land. Command module auto-landed in Earth's ocean. Significant exposure to this risk in 0-G areas of Lunar transit vehicles and 0-G EVA. Teleoperator frame of reference integration problems potentially a factor in Lunar surface operations. [Mars]: Even if Earth and Mars landings are nominally auto-landed, some degree of maneuvering and contingency manual control will be needed for landing at unprepared or contingency sites. Effects of 4-6 month adaptation to 0-G during transit to Mars on astronaut's ability to transition to Mars 1/3 g are unknown. However, large radius continuous AG may be possible. On return to Earth, pilot will have adapted to 0-G for 4-6 months, and ISS experience indicates many will experience strong landing vertigo. Significant exposure to this risk in 0-G areas of Mars transit vehicles and 0-G EVAs. Teleoperator frame of reference integration problems potentially a factor in Mars surface operations
Enabling Questions [Priority on scale of 1(high) to 5 (low)]	
15a.	What are the physiological bases for spatial disorientation, perceptual illusions, and vertigo? [ISS 1 Moon 1, Mars 1]
15b.	What combinations of visual, vestibular, and haptic cues cause spatial disorientation, perceptual illusions, and vertigo during and after g-transitions? [ISS 2 Moon 2, Mars 2]
15c.	Can g-transition-related spatial disorientation, perceptual illusions, and vertigo be predicted from mathematical models? [ISS 3 Moon 3, Mars 3]
15d.	What individual physiological and behavioral characteristics contribute to the large inter-individual differences in neurovestibular symptoms and signs? [ISS 1 Moon 1, Mars 1]
15e.	What individual physiological and behavioral characteristics will best predict susceptibility and adaptability? [ISS 3 Moon 3, Mars 3]
15f.	What is the physiological basis for context-specific-adaptation? [ISS 1 Moon 1, Mars 1]

15g.	To what extent can neurovestibular adaptation to weightlessness and/or AG take place in context-specific fashion, so crewmembers can be adapted to multiple environments and switch between them without suffering disorientation or motion sickness? [ISS 2 Moon 2, Mars 2]
15h.	What pre-flight training techniques (e.g. virtual reality simulations, parabolic flight) can be used to alleviate the risks of spatial disorientation, perceptual illusions, and vertigo as astronauts launch, enter, and adapt to 0-G? [ISS 2 Moon 2, Mars 2]
15i.	What in-flight training techniques (e.g. virtual reality simulations, treadmill with vibration isolation system, artificial gravity) can be used to alleviate the risks of vertigo, disorientation, and perceptual illusions as astronauts land and (re)adapt to Earth, Moon, or Mars gravity? [ISS 3 Moon 3, Mars 3]
15j.	How can voluntary head movements during entry and landing be used to accelerate re-adaptation? [ISS 3 Moon 3, Mars 3]
15k.	Is adaptation to the lunar gravity environment sufficient to reduce incidence of landing vertigo upon return to Earth? [ISS N/A, Moon 3, Mars N/A]
15l.	What AG exposure regimens (G-level, angular velocity, duration, and repetition) will ameliorate the bone, muscle, cardiovascular, and vestibular deconditioning associated with hypogravity during surface operation phases of a mission? [ISS N/A, Moon 5, Mars 5]
15m.	What AG exposure regimens (G-level, angular velocity, duration, and repetition) will ameliorate the bone, muscle, cardiovascular, and vestibular deconditioning associated with hypogravity during transit phases of a mission? [ISS N/A, Moon N/A, Mars 5]
15n.	What level of supervisory control will mitigate the landing vertigo risk in landing on the Moon, Mars, and Earth? [ISS 4 Moon 4, Mars 4]
15o.	How can traditional clinical vestibular rehabilitation techniques be employed to usefully accelerate re-adaptation following g-transitions? [ISS 3 Moon 3, Mars 3]
15p.	What objective assessment techniques can be used to determine crew readiness to return to normal activities following g transitions? [ISS 2 Moon 2, Mars 2]
Related Risks	Proposed as SHFE shared risk (none of current SHFE risks target this specific area, however.)
Important References	McCluskey, R., Clark, J., Stepaniak, P. (2001) Correlation of Space Shuttle Landing Performance with Cardiovascular and Neurological Dysfunction Resulting from Space flight. (Significant correlation between post-flight neurovestibular signs and shorter, faster, harder landings.)
	Young, L., H. Hecht, et al. (2001). "Artificial gravity: head movements during short radius centrifugation." Acta Astronautica 49(3-10): 215-226.
	Young, L. R. (1999). Artificial gravity considerations for a Martian exploration mission. In B. J. M. Hess & B. Cohen (Eds.), Otolith function in spatial orientation and movement, 871 (pp. 367-378). NY, NY: New York Academy of Sciences.
	Guedry, F. E. and A. J. Benson (1978). "Coriolis cross-coupling effects: Disorienting and nauseogenic or not?" Aviation, Space, and Environmental Medicine 49(1): 29-35.
	Baldwin, et al (1997) NASA Task Force on Countermeasures, Final Report. Appendix E
	Paloski, W. H., & Young, L. R. (1999). Artificial gravity workshop: Proceedings and recommendations. NASA/NSBRI Workshop Proceedings.
	Reschke, M. F., J. J. Bloomberg, et al. (1994). Neurophysiological Aspects: Sensory and Sensory-Motor Function. Space Physiology and Medicine. A. E. Nicogossian, Lea and Febiger.

Risk Title: Impaired Movement Coordination Following G-Transitions

Primary Risk Area	**Neurovestibular Adaptation**		
Risk Number	16		
Risk description	When astronauts adapted to 0-G transition to an Earth, Moon, or Mars gravitational environment, balance, locomotion, and eye-head coordination are transiently disrupted. Some symptoms may be masked by sensory substitution, only to emerge unexpectedly in response to changing sensory affordance contexts. Muscle atrophy and orthostatic hypotension may also contribute to post-flight balance and locomotion impairment. Some long duration crewmembers have been unable to egress the spacecraft unassisted in 1-G, so affected crew are at increased risk in an emergency at or soon after landing. There are large individual differences, but recovery of normal abilities requires several days to weeks. Recovery time increases as the 0-G exposure time increases. Lower extremity coordination is often the slowest to return. Post-flight rehabilitation currently employs only traditional methods, and may not be optimal. Sensory-motor changes on long duration flights increases the potential risk of post-landing falls and bone fractures, and delays safe return to normal daily activities (running, driving, and flying).		
Context/Risk Factors	Zero-g exposure duration. The longer a crewmember is exposed to 0-G, generally the more profound and long lasting the post-flight symptoms. 2) Physical activity leading to head movement, or requiring visual acuity (e.g. running, operation of a vehicle or aircraft). 3) Muscle alterations and atrophy due to lack of appropriate 0-G exercise. 4) Cardio-regulatory changes or reduced blood volume increasing susceptibility to fainting.		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Yellow	Yellow	Yellow
Specific current countermeasure(s) or mitigation(s)	[ISS]: Quantitative post-flight tests of spontaneous, positional and positioning nystagmus, postural stability, dynamic visual acuity, and gait (TRL/CRL8). Traditional clinical rehabilitation techniques. [Moon and Mars]: None		
Specific projected countermeasure(s) or mitigation(s)	[ISS]: 1) Quantitative post-flight tests of gaze stability, and locomotion and corner turning stability (TRL 6, CRL 6). 2) General or G-specific pre-adaptation techniques, (e.g. in-flight or pre-flight artificial gravity; sensory-motor generalization training techniques (CRL2) 3) 1-G balance prostheses (e.g. tactile vest, TRL/CRL6) [Moon]: Pre-flight or in-flight g- specific pre-adaptation techniques, (e.g. artificial gravity) (CRL2, TRL1) [Mars]: Improved EVA suits designed to mechanically mitigate fracture risk in the event of falls. G-specific pre-adaptation for Mars landing (e.g. short radius intermittent or large radius continuous artificial gravity) and return to Earth (CRL2, TRL1)		

Justification/Rationale for Risk	[ISS]: Shuttle post-landing emergency egress requires crew to stand up, operate a hatch, attach and lower themselves on a tether, and run away from the vehicle. Cardiovascular and musculo-skeletal countermeasures have mitigated the incidence of muscle weakness, fatigue, and fainting, but many returning crews still exhibit clinically and operationally significant post-flight neurovestibular signs. Long duration crews currently undergo a post-flight physical rehabilitation program based on traditional techniques. Flight surgeons have taken a conservative clinical approach, and no NASA crewmembers have had post-flight fractures or auto accidents. However, none have been able to run 1000 feet on a treadmill on landing day. Animal experiments indicate the vestibular system may play a role in cardiovascular orthostatic regulation. [Moon]: Apollo EVA crews adopted a loping gait in the 1/6 g lunar environment. No reported vertigo and coordination problems. Fracture risks in 1/6 g likely minimal. Primary risks are after return to Earth after long duration (44 day) missions. [Mars]: Mars landings may be in unprepared areas, so posture and locomotion ability in 1/3 g immediately after landing is potentially important in emergencies. Fracture risk in 1/3 g not yet determined, and will depend on countermeasures available in transit vehicle. Mars transit vehicles may use intermittent or continuous AG to pre-adapt crews for Mars surface operations, and to prepare crews for return to Earth.
Enabling Questions [Priority on scale of 1(high) to 5 (low)]	
16a.	What are the physiological bases for disruption of balance, locomotion, and eye-head coordination following g-transitions? [ISS 1 Moon 1, Mars 1]
16b.	Can disruption of balance, locomotion, and eye-head coordination following g-transitions be predicted from mathematical models? [ISS 3 Moon 3, Mars 3]
16c.	What individual physiological and behavioral characteristics contribute to the large inter-individual differences in neurovestibular symptoms and signs? [ISS 1 Moon 1, Mars 1]
16d.	What individual physiological and behavioral characteristics will best predict susceptibility and adaptability? [ISS 3 Moon 3, Mars 3]
16e.	What is the physiological basis for context-specific-adaptation? [ISS 1 Moon 1, Mars 1]
16f.	To what extent can neurovestibular adaptation to weightlessness and/or AG take place in context-specific fashion, so crewmembers can be adapted to multiple environments and switch between them without suffering impaired balance control and/or movement coordination? [ISS 2 Moon 2, Mars 2]
16g.	What in-flight training techniques (e.g. virtual reality simulations, treadmill with vibration isolation system, artificial gravity) can be used to alleviate the risks of impaired balance control and movement coordination as astronauts land and (re)adapt to Earth, Moon, or Mars gravity? [ISS 3 Moon 3, Mars 3]
16h.	Is adaptation to the lunar gravity environment sufficient to reduce incidence of sensory-motor balance and coordination problems upon return to Earth? [ISS N/A, Moon TBD, Mars N/A]
16i.	What AG exposure regimens (G-level, angular velocity, duration, and repetition) will ameliorate the bone, muscle, cardiovascular, and vestibular deconditioning associated with hypogravity during surface operation phases of a mission? [ISS N/A, Moon TBD, Mars TBD]
16j.	What AG exposure regimens (G-level, angular velocity, duration, and repetition) will ameliorate the bone, muscle, cardiovascular, and vestibular deconditioning associated with hypogravity during transit phases of a mission? [ISS N/A, Moon N/A, Mars TBD]

16k.	How can traditional clinical vestibular rehabilitation techniques be employed to usefully accelerate re-adaptation following g-transitions? [ISS TBD, Moon TBD, Mars TBD]
16l.	What objective assessment techniques can be used to determine crew readiness to return to normal activities following g transitions? [ISS TBD, Moon TBD, Mars TBD]
16m.	How can pre-flight or in-flight sensory-motor training or sensory aids improve post-landing postural and locomotor control and orthostatic tolerance? [ISS TBD, Moon TBD, Mars TBD]
16n.	To what extent can crew "learn how to learn" by adapting to surrogate sensory-motor rearrangements? [ISS TBD, Moon TBD, Mars TBD]
16o.	What are the relative contributions of sensory-motor adaptation, neuromuscular deconditioning, and orthostatic intolerance to post-flight neuro-motor coordination, ataxia, and locomotion difficulties? [ISS TBD, Moon TBD, Mars TBD]
16p.	What posture, locomotion and gaze deficits result from transition to Mars gravity and Moon gravity? [ISS N/A, Moon TBD, Mars TBD]
Related Risks	[ISS]: Disorientation, Perceptual Illusions and Vertigo, Cardiovascular discipline: impaired response to orthostatic stress. Nutrition and Rehabilitation discipline: balance and locomotion rehabilitation. [Moon and Mars]: Disorientation, Perceptual Illusions and Vertigo.
Important References	Paloski, W. H., M. F. Reschke, et al. (1992). Recovery of postural equilibrium control following space flight. Sensing and Controlling Motion: Vestibular and Sensorimotor Function. B. Cohen, D. L. Tomko and F. E. Guedry. NY, Annals of the NY Academy of Sciences. 656: 747-754
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	Young, L. R. (1999). Artificial gravity considerations for a Martian exploration mission. In B. J. M. Hess & B. Cohen (Eds.), Otolith function in spatial orientation and movement, 871 (pp. 367-378). NY, NY Academy of Sciences)
	Richards J. T., Clark J. B., Oman C. M. and Marshburn T. H. (2002) Neurovestibular Effects of Long-Duration Space flight: A Summary of Mir Phase 1 Experiences, NSBRI/NASA technical report, p. 1-33, also Journal of Vestibular Research 11(3-5): 322
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	Guedry, F. E. and A. J. Benson (1978). "Coriolis cross-coupling effects: Disorienting and nauseogenic or not?" Aviation, Space, and Environmental Medicine 49(1): 29-35.
	Lackner JR, DiZio P. (2000) Human orientation and movement control in weightlessness and AG environments. Exp. Brain Res. 130: 2-26
	Baldwin, et al (1997) NASA Task Force on Countermeasures, Final Report. Neurovestibular Countermeasures Appendix E-26
	Bloomberg JJ, Mulavara AP (2003). Changes in walking strategies after space flight. IEEE Engineering in Medicine and Biology Magazine, 22(2): 58-62.

Risk Title: Motion Sickness

Primary Risk Area	**Neurovestibular Adaptation**		
Risk Number	17		
Risk description	Motion sickness symptoms frequently occur in crewmembers during and after g-transitions. Symptoms include nausea, stomach awareness, gastrointestinal stasis, anorexia, dehydration, and less overt but operationally significant symptoms such as "space stupids," irritability, profound fatigue ("sopite" syndrome), and changes in sleep-wake cycle. Motion sickness symptoms decrease crew work capacity, vigilance, and motivation, impair short-term memory, and increase the likelihood of cognitive error. Although only 10-20% of Shuttle crews vomit, 75% experience symptoms for the first 2-4 days in 0-G, and many experience similar symptoms for hours to days after landing. Several crewmembers have remained symptomatic during flight for up to 2 weeks. Current anti-motion sickness drugs are only partially effective. Though they appear to reduce symptoms and delay onset, they have significant side effects that prevent regular prophylactic use. While rotational AG (AG) has great potential as a bone, muscle, cardiovascular, and vestibular countermeasure, head movements out of the plane of rotation may lead to motion sickness. How provocative the AG stimulus is at levels between 0 and 1-G, and how rapidly and completely humans can adapt is largely unknown, and cannot be fully determined in ground laboratories. If motion sickness drives an EVA crewmember to vomit in the extant extravehicular mobility unit, EMU, a complete shutdown of the primary and secondary oxygen supplies could occur, leaving only a few minutes of residual oxygen in the suit, creating a serious emergency. Vomit on the faceplate could also block vision. Even if the crewmember survives, vomit is biologically active, so the EMU cannot be reused, and must be returned to the ground for refurbishment.		
Context/Risk Factors	1) Initial week of exposure to altered gravity. 2) Head movements and visual cues causing frame-of-reference illusions. 3) Diseases, conditions or drugs which cause nausea and vomiting (gastroenteritis, contaminated food or water, certain medications, pregnancy)		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Green	Green	Green
Specific current countermeasure(s) or mitigation(s)	• Head and body movement restriction • Oral Scopolamine/Dexedrine • Oral Promethazine/Ephedrine • Intramuscular promethazine injection.		
Specific projected countermeasure(s) or mitigation(s)	New administration methods for rapid, reliable relief with fewer side effects. (TRL\CRL 6) Techniques to quantify cognitive deficits (TRL/CRL 6)		Large radius continuous or short radius intermittent AG

Justification/Rationale for Risk	[ISS]: Mercury and Gemini crews were restrained in their capsules, and did not report sickness. Primary stimuli are clearly head movements and frame-of-reference illusions resulting from 3D movement. Crews move slowly and stay upright to limit symptoms. Prior space flight experience reduces susceptibility. Apollo, Skylab and early Shuttle crews took prophylactic oral scopolamine/dexedrine or promethazine/ephedrine, with limited effectiveness, and sometimes objectionable side-effects. Symptoms are currently treated with intramuscular promethazine and sleep/rest, but injections leave a painful sore spot. Early US and Russian programs impelemented aerobatic flight and various forms of extreme vestibular stimulation as pre-flight countermeasures, and use of Coriolis induced sickness susceptibility as a predictor, without demonstrable success, though many crew believe aerobatic and parabolic flight practice should be helpful. NASA developed TransdermScop patch in early 80s, but effectiveness and side effects were too variable for deployment. Russians deployed neck restraints and foot-pressure-inducing boots, but there is no data showing effectiveness. Biofeedback/autogenic training techniques can be effective against laboratory induced sickness, but flight evaluations have been equivocal, and techniques may not be usable by everyone. [Moon}: Several Apollo crews retrospectively reported symptoms in Earth orbit, and on the way to the moon. No symptoms reported on lunar surface. One report of symptoms during 0-G return. [Mars]: Crew will be potentially susceptible to motion sickness for several days after each major G-level change during the mission (1-G to 0-G to AGto 0-G to 0-G to Martian-g to 0-G to artificial-g to 0-G to Earth-g.)
Enabling Questions [Priority on scale of 1(high) to 5 (low)]	
17a.	What are the physiological mechanisms that trigger vomiting in space motion sickness? [ISS 1 Moon 1, Mars 1]
17b.	What is the physiological basis of the emetic linkage between vestibular and emetic centers? [ISS 2 Moon 2, Mars 2]
17c.	What individual physiological and behavioral characteristics contribute to the large inter-individual differences in neurovestibular symptoms and signs? [ISS 1 Moon 1, Mars 1]
17d.	What individual physiological and behavioral characteristics will best predict susceptibility and adaptability? [ISS 3 Moon 3, Mars 3]
17e.	What is the physiological basis for context-specific-adaptation? [ISS 1 Moon 1, Mars 1]
17f.	To what extent can neurovestibular adaptation to weightlessness and/or AG take place in context-specific fashion, so crewmembers can be adapted to multiple environments and switch between them without suffering disorientation or motion sickness? [ISS 3 Moon 3, Mars 3]
17g.	What pre-flight training techniques (e.g. virtual reality simulations, parabolic flight) can be used to alleviate the risks of space motion sickness? [ISS 4 Moon 4, Mars 4]
17h.	What in-flight training techniques (e.g. virtual reality simulations, treadmill with vibration isolation system, artificial gravity) can be used to alleviate the risks of space motion sickness as astronauts land and (re)adapt to Earth, Moon, or Mars gravity? [ISS 4 Moon 4, Mars 4]
17i.	Is adaptation to the lunar gravity environment sufficient to reduce incidence of motion sickness upon return to Earth? [ISS N/A, Moon 4, Mars N/A]
17j.	What AG exposure regimens (G-level, angular velocity, duration, and repetition) will ameliorate the bone, muscle, cardiovascular, and vestibular deconditioning associated with hypogravity during surface operation phases of a mission? [ISS N/A, Moon 5, Mars 5]
17k.	What AG exposure regimens (G-level, angular velocity, duration, and repetition) will ameliorate the bone, muscle, cardiovascular, and vestibular deconditioning associated with hypogravity during transit phases of a mission? [ISS N/A, Moon N/A, Mars 5]

17l.	How does susceptibility to motion sickness due to Coriolis forces and cross-coupled canal stimuli vary as a function of g-levels between 0-G and 1-G, and also on rpm, radius, and head orientation during AG? [ISS N/A, Moon 1, Mars 1]
17m.	What are the best methods for quantifying the symptoms and signs of motion sickness and associated performance decrements and drug side effects in a non-intrusive way? [ISS 2, Moon 2, Mars 2]
17n.	What better ways can be found to administer anti-motion sickness drugs to provide more rapid and reliable relief, with fewer objectionable side effects? [ISS 3, Moon 3, Mars 3]
17o.	Do scopolamine and promethazine prevent or impair sensory-motor adaptation to 0-G? [ISS 4, Moon 4, Mars 4]
17p.	What new drugs will more specifically prevent nausea, fatigue, memory and vigilance deficits without side effects? [ISS 4, Moon 4, Mars 4]
17q.	Can drugs be developed to effectively block the emetic linkage without unacceptable side effects? [ISS 4, Moon 4, Mars 4]
17r.	Can operationally practical, non-pharmacologic techniques be developed that are effective against motion sickness? [ISS 4, Moon 4, Mars 4]
17s.	Is 1/6 g lunar gravity or 3/8 Mars gravity adequate to prevent all cases of motion sickness? [ISS N/A, Moon 4, Mars 4]
Related Risks	Potential shared risk with Human Sleep, Performance and Chronobiology.
Important References	Guedry, F. E. and A. J. Benson (1978). "Coriolis cross-coupling effects: Disorienting and nauseogenic or not?" Aviation, Space and Environmental Medicine 49(1): 29-35.
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	Reschke, M. F., J. J. Bloomberg, et al. (1994). Neurophysiological Aspects: Sensory and Sensory-Motor Function. Space Physiology and Medicine. A. E. Nicogossian, Lea and Febiger.
	Cowings, P.S. (1990). Autogenic-Feedback Training: A Preventive Method for Motion and Space Sickness. In: (G. Crampton (ed.). Motion and Space Sickness. Boca Raton Florida: CRC Press. Chapter 17, Pp.354-372
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Risk Title: Inadequate Nutritional Requirements

Primary Risk Area	Nutrition

Risk Number	18
Risk description	Without scientifically supported nutritional requirements, a food system cannot be developed to support astronaut health. Nutritional requirements for space include fluids, macronutrients, micronutrients and compounds or elements that may be essential and may include compounds that may be required to optimize health status such as lipids, energy distribution (e.g., % calories from carbohydrate), fiber and non-nutritive factors such as various phytochemicals, etc. Requirements must take into account any of the changes in the sensory system that might influence taste and smell that influence intake and the role of countermeasure-induced alterations on nutrient requirements. The symptoms of short-term nutritional inadequacies include impaired physical and cognitive capacities and the long-term effects include decrements in bone density, cardiovascular disease and cancer risk. The effect or outcome of nutritional deficiencies include: 1) too little food (nutrients) on board to complete the mission, 2) inadequacies that lead to crewmember failure/death and 3) inability to return to flight status because of inability to rehabilitate the crewmember. The risks to various crewmembers include various physical and cognitive deficiencies, possible visual and cognitive deficits in pilots and inability to perform EVA due to physical deficits or excess damage due to radiation exposure.
Context/Risk Factors	Undefined nutritional requirements causing inability to provide nutritional foods, exacerbate substandard food intakes, countermeasure-induced alterations in nutrient requirements leading to poor countermeasure performance; e.g., bone, muscle, immune system and radiation protection. Psychosocial factors, elevated stress and boredom all contribute to this risk. For missions where *in situ* food production are required, failure of this system would be an associated risk as well.
Specific current countermeasure(s) or mitigation(s)	The countermeasure is the provision of adequate diet to maintain health and to provide correct nutrient and non-nutrient proportions to prevent problems due to bone and muscle loss, radiation and potential changes in immune function. This has not been implemented (e.g., food system limitations), utilized (e.g., inadequate intake), or evaluated (e.g., lack of research) fully to determine whether the current provisions are fully meeting requirements.
Specific projected countermeasure(s) or mitigation(s)	Food, nutrients, improved dietary compliance and counseling, enhanced food system. Provide diet and nutritional supplementation that ensures and/or enhances the effectiveness of other countermeasures. Nutritional requirements must include the role of food in psychosocial needs. Refined nutritional requirements, understanding and implementing an acceptable food system and understanding the psychological benefits of food all may serve as potential countermeasures. [TRL/CRL TBD]

Design Reference Mission	ISS	Lunar	Mars
RYG Risk Assessment	Green	Green	Yellow
Justification/Rationale for Risk	Essentially all US crews have experienced nutritional deficiencies. Limited foods, physiological changes, stress and other factors may have consequences for physical and cognitive performance. Inadequate micronutrient or vitamin intake could adversely affect crew health, making determination of all required nutrients (absorption, metabolism, excretion) a priority. Furthermore, nutrition/nutrients may play a role in counteracting the negative effects of space flight (e.g., radiation, bone and muscle loss). These have yet to be fully explored.		
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
18a.	What are the nutritional requirements for extended stay ISS missions, including (but not limited to): calories, protein, calcium, iron, antioxidants, iodine, vitamin D, sodium, potassium? [ISS 1, Moon 1, Mars 1]		
18b.	What are the potential impacts of countermeasures on nutritional requirements or nutritional status? [ISS 1, Moon 1, Mars 1]		
18c.	What are the decrements in nutritional status due to long-term LEO, lunar, and exploration missions? Can these be ameliorated? [ISS 1, Moon 1, Mars 1]		
18d.	What are the means of monitoring nutritional status during the mission? [ISS 3, Moon 3, Mars 3]		
18e.	What monitoring (biochemical, anthropometric, clinical assessments) during rehabilitation is required? [ISS 3, Moon 3, Mars 3]		
18f.	What level of dietary counseling is needed for crewmembers during rehabilitation? [ISS 3, Moon 3, Mars 3]		
18g.	Can general nutrition or specific nutrient countermeasures mitigate the negative effects of space flight on bone, muscle, cardiovascular and immune, systems and protect against damage from radiation? [ISS 1, Moon 1, Mars 1]		
18h.	What is the role of adequate nutrition/weight maintenance on crew health (specifically bone, muscle and cardiovascular adaptation)? [ISS 1, Moon 2, Mars 1]		
18i.	What level of dietary counseling is needed for crewmembers pre-flight? [ISS 1, Moon 2, Mars 1]		
18j.	How does on orbit exercise affect nutritional requirements and vice versa? [ISS 1, Moon 2, Mars 1]		
18k.	Can nutrition mitigate radiation induced cataractogenesis and carcinogenesis? [ISS 1, Moon 1, Mars 1]		
18l.	Are there long-term effects of disease risk post-flight and can nutritional countermeasures be preventative? [ISS 1, Moon 2, Mars 1]		

Related Risks	1. Accelerated bone loss and fracture risk 2. Impaired fracture healing 4. Renal stone formation 6. Diminished cardiac and vascular function 13. Skeletal muscle atrophy resulting in reduced strength and/or endurance 14. Increased susceptibility to muscle damage 17. Motion sickness 31. Carcinogenesis 32. Acute and late CNS risks 33. Other degenerative tissue risks 34. Radiation effects on fertility, sterility and heredity 35. Acute radiation syndromes 45. Manage waste 46. Provide and maintain bioregenerative life support systems 47. Provide and recover potable water 48. Inadequate mission resources for the human system
Important References	*Nutrition* 18:793-936, 2002. (volume dedicated to nutrition and space, >20 articles)
	NASA Johnson Space Center. Nutritional Requirements for International Space Station Missions Up To 360 Days. JSC-28038; 1996.

Autonomous Medical Care

Risk Title: Monitoring and Prevention

Primary Risk Area	Medical Care		
Risk Number	19		
Risk description	Monitoring and Prevention (Health Tracking, Prophylaxis & Disease Prevention). The primary means to reduce the risk of life and/or mission-threatening medical conditions is to prevent those conditions from happening. The second most effective means to reduce such risk is to monitor for medical conditions so as to catch them at an early stage to treat.		
Context/Risk Factors	Pre-flight screening, pre-mission screening, medical history, family history		
Specific current countermeasure(s) or mitigation(s)	Selection critera for astronauts to become active and to be selected for a mission. Annual comprehensive physical exam. In-flight examination.		
Specific projected countermeasure(s) or mitigation(s)	Additional screening criteria. Better equipment to monitor and track in-flight.		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Yellow	Yellow	Red
Justification/Rationale for Risk	TBD		
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
	Health Tracking		
19a.	Define the key parameters for health screening and early detection. [ISS 4, moon 2, Mars 1]		
19b.	Identify what resources and technologies are required for routine health monitoring, including examination, laboratory, imaging and adaptation for operation in reduced-G environments. [ISS 4, moon 2, Mars 1]		
19c.	What diagnostic imaging technologies and procedures need to be developed and/or adapted to support the primary, secondary and tertiary prevention of illness and injury? [ISS 3, moon 2, Mars 1]		
19d.	Identify the parameters and sensors needed to monitor health and performance in crewmembers performing EVA. [ISS 4, moon 2, Mars 2]		
19e.	Identify the investigations needed to discriminate between terrestrial and space flight norms in order to allow early detection of illness and injury. [ISS 3, moon 2, Mars 2]		
19f.	What is space-normal physiology? [ISS 4, moon 3, Mars 3]		
19g.	What are the signs, symptoms or abnormal examination findings (including laboratory) associated with illness and injury in reduced-G? [ISS TBD, Moon TBD, Mars TBD]		
19h.	How do alterations in space flight-associated physiology interact across body systems? [ISS 4, moon 3, Mars 3]		
19i.	Identify the appropriate informatics tools to automate monitoring crew health (i.e., prompting screening evaluations, off-nominal value detection, intelligent diagnostic work-up), in order to free-up crew time. [ISS 2, moon 1, Mars 1]		

	Prophylaxis/Disease Prevention
19j.	Identify the ideal set of nutritional and medical prophylaxis and primary and secondary preventive measures to reduce the risk of space illness. (such as medical countermeasures for known conditions e.g., bisphosphonates for loss of BMD). [ISS 3, moon 3, Mars 2]
19k.	Identify the primary, secondary and tertiary prevention strategies needed to mitigate the risk of anticipated environmental exposures to toxic substances and radiation.(i.e., shielding, nutritional and medical prophylaxis such as agents to augment cellular defenses, immune surveillance, etc.). [ISS 2, moon 1, Mars 1]
19l.	What are the essential technologies, resources, procedures, skills and training necessary to provide effective primary prevention strategies to mitigate each of the conditions listed in the SMCCB-approved Space Medicine Condition List (catalogued in the online Patient Condition Database)? [ISS 4, moon 3, Mars 2]
19m.	What are the essential technologies, resources, procedures, skills and training necessary to provide effective secondary prevention strategies to mitigate each of the conditions listed in the SMCCB-approved Space Medicine Condition List (catalogued in the online Patient Condition Database)? [ISS 4, moon 3, Mars 2]
Related Risks	All Countermeasures Risks, Behavior and Performance
Important References	TBD

Risk Title: Major Illness & Trauma

Primary Risk Area	Medical Care		
Risk Number	20		
Risk description	Major Illness & Trauma (Diagnosis, Management, CPR, BCLS, ACLS, BTLS, ATLS, DCS, Toxic Exposure- Detection and Management, Surgical Management, Medical Waste Management). There is a risk of major illness that increases with length of mission. There is always a risk of trauma which can vary according to activities (e.g. construction, vehicle driving, etc.) Lack of capability to treat these major illnesses and injuries poses a threat to life and mission.		
Context/Risk Factors	TBD		
Specific current countermeasure(s) or mitigation(s)	ISS Medical Kit, Debibrillator, Ventilator, transport to terrestrial care facility		
Specific projected countermeasure(s) or mitigation(s)	TBD		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Yellow	Red	Red
Justification/Rationale for Risk	TBD		
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
20a.	What are the essential technologies, resources, procedures, skills and training necessary to provide effective tertiary prevention strategies to mitigate each of the conditions listed in the SMCCB-approved Space Medicine Condition List (catalogued in the online Patient Condition Database)? [ISS 3, moon 1, Mars 1]		
	Major Illness Diagnosis		
20b.	Identify the technologies for employing decision support techniques for diagnostic assistance of the crew medical personnel, emphasizing autonomy in decision-making from ground resources and based on known space flight illnesses and injuries and expedition analog experience. [ISS 2, moon 1, Mars 1]		
20c.	Define the appropriate role and resources required for telemedical consultation for the diagnosis and management of major illnesses. [ISS 3, moon 2, Mars 1]		
	Major Illness Treatment		
20d.	Identify and adapt for reduced-G operation the resources, procedures and technologies are required for treatment of major illnesses, emphasizing autonomy from ground resources and based on known space flight illnesses and injuries and expedition analog experience. [ISS 2, moon 1, Mars 1]		
20e.	Identify appropriate synergistic and alternative management strategies for reducing the morbidity of major illnesses during space flight. [ISS TBD, Moon TBD, Mars TBD]		
20f.	What procedures and protocols are necessary for rehabilitation after an acute medical illness or trauma? [ISS 4, moon 3, Mars 1]		
	CPR/BCLS/ACLS (Cardiac Life Support)		
20g.	What is the most effective means of conducting life support operations in the space flight milieu, to include identification and modification of the resources and procedures for reduced-G? [ISS 3, moon 2, Mars 1]		

20h.	Identify the optimal resources and procedures for post-resuscitation management of the ill/injured crewmember and modify for reduced-G operations. [ISS 2, moon 1, Mars 1]
	BTLS, ATLS (Trauma Life Support)
20i.	What are the resources and procedures needed to perform basic and advanced management of trauma? [ISS 3, moon 1, Mars 1]
20j.	What are resources required for telemedical consultation for the diagnosis and management of major trauma? [ISS 3, moon 2, Mars 1]
	Decompression Illness (DCS) & Other Environmental Illness
20k.	What is the most effective pre-EVA DCS prevention strategy to include pre-breathe with various gases, exercise and other medical measures? [ISS 5, moon NA if 5psi base, Mars NA if 5psi base]
20l.	What are the appropriate screening procedures to minimize predispositions for DCS? [ISS 4, moon NA if 5psi base, Mars NA if 5psi base]
20m.	Identify the resources and techniques for early diagnosis of DCS signs and symptoms, including the use of Doppler U/S and other bubble detection technologies. [ISS 4, moon NA if 5psi base, Mars NA if 5psi base]
20n.	What are the best methods for predicting DCS risk and for reducing the risk, based on understanding of the physiological mechanism for bubble formation and propagation, employing best available knowledge from flight and analog environment experience? [ISS 4, moon NA if 5psi base , Mars NA if 5psi base]
20o.	Identify and adapt for reduced-G operations the most effective yet energy and space-efficient, as well as safe means of managing DCS in the space flight milieu, including the use of hyperbaric oxygen delivery and other promising technology. [ISS 3, moon 2, Mars 1]
20p.	What is the actual risk of space-related DCS? (from both de novo physiological causes and through acute environmental insult – e.g., leaking module or damaged EMU etc.?) [ISS 3, moon 3, Mars 3]
20q.	What are the operational and medical impacts of off-nominal performance of DCS countermeasures? [ISS 4, moon 3, Mars 3]
20r.	What are the risk factors that can increase the likelihood of DCS, such as the presence of Patent Foramen Ovale (PFO)? [ISS 4, moon 3, Mars 2]
20s.	What is the likelihood of surviving an acute environmental insult severe enough to cause damage to the vehicle or spacesuit? [ISS 2, moon 2, Mars 2]
20t.	Is it possible and what are the DCS risk mitigation options for interplanetary EVA (e.g., moon and Mars) given that a tri-gas breathing mixture including argon is present? (4) [ISS 4, moon 4, Mars 4]
20u.	What is the role of individual susceptibility, age and gender on the risk of DCS during NASA operations involving decompression? (3) [ISS 4, moon 3, Mars 3]
20v.	What are the available and new technologies needed to provide hyperbaric treatment options on the ISS and future habitats (or vehicles) beyond LEO (e.g., on the moon or Mars)? [ISS 3, moon 2, Mars 1]
20w.	What is the correlation between the detection/existence of gas phase creation in the bloodstream and development of clinically significant DCS? [ISS 4, moon 3, Mars 3]
	Toxic Exposure Detection
20x.	Identify the signs and symptoms secondary to toxic chemical exposure and radiation in reduced-G environments. [ISS 2, moon 1, Mars 1]

	Toxic Exposure/Management
20y.	What are the resources and procedures for the mitigation of toxic exposures? [ISS 3, moon 1, Mars 1]
20z.	What primary prevention strategies (such as crew screening and selection criteria) should be developed and implemented to identify individuals who are at increased risk for developing hypersensitivity or allergies to space flight compounds, exposures, or payloads? [ISS 3, moon 2, Mars 2]
20aa.	What secondary prevention strategies (i.e., countermeasures) should be developed and implemented to prevent adverse reactions to toxic exposures (e.g., sleep, nutritional, medications, stress reduction, shielding, protective equipment, etc.)? [ISS 3, moon 2, Mars 2]
Surgical Management	
20bb.	What are the resources and procedures needed for surgical management of illness and injury and major trauma? [ISS 3, moon 1, Mars 1]
20cc.	What are the appropriate roles and resources required for telemedical consultation for the surgical management of major illnesses? [ISS 3, moon 2, Mars 1]
20dd.	What are the issues surrounding wound care? [ISS 4, moon 2, Mars 2]
Medical Waste Management	
20ee.	What are the most effective means of management and disposal of medical waste within the surgical milieu? [ISS 2, moon 1, Mars 1]
Related Risks	TBD
Important References	TBD

Risk Title: Pharmacology of Space Medication Delivery

Primary Risk Area	Medical Care		
Risk Number	21		
Risk description	Pharmacology of Space Medication Delivery (Space flight Physiology Effects – Pharmacodynamics/Pharmocokinetics, Drug Stowage/Utilization/Replenishment, Drug Use Optimization), . If issues relating to pharmaceutical stowage, generation, effectiveness, and administration methods are not solved then we may be unable to treat some medical conditions during flight, resulting in a threat to both life and mission.		
Context/Risk Factors	Radiation environment, limited or no resupply, micro-gravity		
Specific current countermeasure(s) or mitigation(s)	Resupply		
Specific projected countermeasure(s) or mitigation(s)	TBD		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Yellow	Yellow	Red
Justification/Rationale for Risk	TBD		
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
	Pharmacodynamics/Pharmacokinetics		
21a.	What are the effects of space flight and reduced-G on the absorption, distribution, metabolism, clearance, excretion, clinical efficacy, side effects and drug interactions for medications used in primary, secondary and tertiary prevention of conditions stated in the Space Medicine Condition List? [ISS 2, moon 2, Mars 1]		
21b.	How should the crew and medical team be trained and prepared to recognize and deal with side effects and interaction effects of commonly used medications? [ISS 3, moon 3, Mars 2]		
21c.	What diagnostic, therapeutic and laboratory technologies are necessary to predict (model) and manage medication side effects, interactions and toxicity during space flight? [ISS 3, moon 3, Mars 3]		
21d.	What effect does space adaptation have on drug bio-availability and how can efficacy be enhanced? [ISS 2, moon 2, Mars 1]		
	Drug Stowage/Utilization/Replenishment		
21e.	What is the effect of long-duration space flight on drug stability and what measures can be employed to extend the duration of drug efficacy? [ISS 3, moon 1, Mars 1]		
21f.	Identify appropriate on-orbit/on-station means of drug and intravenous (IV) fluid replenishment appropriate for space operations. [ISS 3, moon 1, Mars 1]		
21g.	What are Biomedical models for drug efficacy? [ISS 4, moon 3, Mars 3]		
	Drug Use Optimization		
21h.	Define the optimal dosages and routes of administration for space flight/ reduced-G clinical effectiveness. [ISS 3, moon 2, Mars 2]		

21i.	Identify efficient means of monitoring druG-levels for therapeutic effect and toxicity and to minimize cross-reaction and negative synergy. [ISS 4, moon 3, Mars 3]
Related Risks	Behavior and Performance, Radiation shielding
Important References	TBD

Risk Title: Ambulatory Care

Primary Risk Area	Medical Care		
Risk Number	22		
Risk description	Ambulatory Care (Minor Illness-Diagnosis, Management; Minor Trauma – Management) The risk of not being able to diagnose and treat minor illnesses and minor trauma can lead to more significant conditions that may threaten limb, life and mission.		
Context/Risk Factors			
Specific current countermeasure(s) or mitigation(s)	ISS Medical Kit		
Specific projected countermeasure(s) or mitigation(s)	TBD		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Green	Green	Yellow
Justification/Rationale for Risk	TBD		
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
	Minor Illness Diagnosis		
22a.	Identify and adapt for reduced-G operations the resources for establishing the diagnosis of minor illnesses, emphasizing autonomy in decision-making from ground resources and based on known space flight illnesses and injuries and expedition analog experience. [ISS 4, moon 2, Mars 1]		
22b.	Define the appropriate role and resources required for telemedical consultation for the diagnosis and management of minor illnesses. [ISS 4, moon 3, Mars 2]		
	Minor Illness Management		
22c.	Identify and adapt for reduced-G operation the resources and procedures required for treatment of minor illnesses, emphasizing autonomy from ground resources and based on known space flight illnesses and injuries and expedition analog experience. [ISS 4, moon 3, Mars 2]		
22d.	Identify appropriate synergistic and alternative management strategies for reducing the morbidity of minor illnesses during space flight. [ISS X, moon X, Mars X]		
	Minor Trauma Management		

22e.	Identify and adapt for reduced-G operations the resources and procedures required for the treatment of minor trauma, emphasizing autonomy from ground resources and based on known space flight illnesses and injuries and expedition analog experience. [ISS 3, moon 1, Mars 1]		
Related Risks	Monitoring & Prevention, Safety		
Important References	TBD		

Risk Title: Return to Gravity/Rehabilitation

Primary Risk Area	Medical Care		
Risk Number	23		
Risk description	Return to Gravity/Rehabilitation. Possibility of deconditioning during space flight to another gravitational body entails the need for rehabilitation once a crewmember returns to gravity. Otherwise the crewmember may not be able to function as needed.		
Context/Risk Factors	TBD		
Specific current countermeasure(s) or mitigation(s)	Exercise during flight, ground support personnel and ground rehabilitation facilities		
Specific projected countermeasure(s) or mitigation(s)	TBD		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Green	Yellow	Red
Justification/Rationale for Risk	TBD		
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
23a.	What are the primary, secondary and tertiary preventive strategies needed to ensure post-landing performance for all DRMs? [ISS 4, moon 4, Mars 1]		
23b.	What are the essential technologies, resources, protocols, skills and training necessary for post landing rehabilitation (including psychological, cardiovascular, neurosensory, musculoskeletal and nutritional)? [ISS 4, moon 4, Mars 1]		
Related Risks	TBD		
Important References	TBD		

Risk Title: Insufficient Data/Information/Knowledge Management & Communication Capability

Primary Risk Area	Medical Care		
Risk Number	24		
Risk description	Insufficient Data/Information/Knowledge Management & Communication Capability. The risk of not being able to get the right data/information/knowledge to the right place at the right time.		
Context/Risk Factors	TBD		
Specific current countermeasure(s) or mitigation(s)	TBD		
Specific projected countermeasure(s) or mitigation(s)	TBD		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Green	Yellow	Red
Justification/Rationale for Risk	TBD		
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
24a.	What decision support technologies are needed to support clinical care? [ISS 4, moon 2, Mars 1]		
24b.	What informatics systems and technology are needed, both for crew and ground support, to optimize medical care? [ISS 3, moon 1, Mars 1]		
24c.	What are the impacts of communication latency on the ability to provide primary, secondary and tertiary prevention during space flight? [ISS 4, moon 4, Mars 1]		
Related Risks	TBD		
Important References	TBD		

Risk Title: Skill Determination and Training

Primary Risk Area	Medical Care		
Risk Number	25		
Risk description	Skill determination and Training. Risk of not having crewmembers with the right medical skills and training to perform the medical procedures needed. Assumption: For Mars, there will be at least one physician, assisted by non-physician space medical care providers.		
Context/Risk Factors	TBD		
Specific current countermeasure(s) or mitigation(s)	TBD		
Specific projected countermeasure(s) or mitigation(s)	TBD		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Green	Yellow	Red
Justification/Rationale for Risk	TBD		
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
25a.	What are the necessary clinical skills/knowledge for a space medicine physician? [ISS 4, moon 1, Mars 1]		
25b.	How can the clinical skills and knowledge of space medical care providers be maintained during missions? [ISS 2, moon 2, Mars 1]		
25c.	What is the optimum crew complement (size, skill sets, etc.) to provide the appropriate medical care for the primary, secondary and tertiary care for the conditions in the Space Medicine Condition List? [ISS 4, moon 3, Mars 1]		
25d.	What techniques can be used to train and maintain the skills of the crew medical personnel to perform specific medical procedures when needed? [ISS 3, moon 1, Mars 1]		
Related Risks	TBD		
Important References	TBD		

Risk Title: Palliative, Mortem and Post-Mortem Medical Activities

Primary Risk Area	Medical Care		
Risk Number	26		
Risk description	Palliative, Mortem and Post-Mortem Medical Activities. As the length of mission and distance from Earth increase, the likelihood that a crewmember will become so ill or injured that he/she cannot survive increases.		
Context/Risk Factors	TBD		
Specific current countermeasure(s) or mitigation(s)	Medical evacuation of ISS		
Specific projected countermeasure(s) or mitigation(s)	TBD		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Yellow	Red	Red
Justification/Rationale for Risk	TBD		
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
Palliative Care			
26a.	What are the specific techniques, resources, protocols, training curricula, skills and equipment (technology) necessary to implement palliative care protocols for in-flight use? [ISS 4, moon 2, Mars 1]		
26b.	What is the policy and procedure for determining a "Do Not Resuscitate" (DNR) status on a Martian mission? [ISS 3, moon 1, Mars 1]		
Declaring Death			
26c.	What are the criteria for death during missions? [ISS 4, moon 3, Mars 2]		
26d.	What are procedures for pronouncing death during missions? [ISS 4, moon 3, Mars 2]		
26e.	What resources and procedures are needed to determine cause of death during a mission? [ISS 4, moon 3, Mars 3]		
26f.	What is the policy and procedure for termination of a "Code" on a Martian mission? [ISS 3, moon 1, Mars 1]		
Cadaver Management			
26g.	What resources, procedures, protocols and technology are required to handle deceased crewmembers? [ISS 3, moon 1, Mars 1]		
Managing Remaining Crew			
26h.	Identify the strategies for psychological stress management and maintaining morale and acceptable functioning and safety of the remaining crewmembers. [ISS 3, moon 1, Mars 1]		
Related Risks	Behavior and Performance		
Important References	TBD		

Behavioral Health and Performance

Risk Title: Human Performance Failure Due to Poor Psychosocial Adaptation

Primary Risk Area	Human Behavior and Performance		
Risk Number	27		
Risk description	Human performance failure due to problems associated with adapting interpersonally to the space environment; poor interpersonal relationships and/or group dynamics; inadequate team cohesiveness; and poor pre-mission preparation.		
Context/Risk Factors	Social isolation; crowding; distance from family and friends; interpersonal tensions; poor communications; scheduling constraints and requirements; sleep disturbances; boredom with available foodstuffs; mechanical breakdowns; incompatible crewmembers, duration of flight; crew autonomy and increased reliance on each other		
Specific current countermeasure(s) or mitigation(s)	• Pre-flight training and teambuilding, • In-flight psychological support**,** • Select-in criteria, • Language and cultural training, • Personal in-flight communications with Earth, • Self-report monitoring of adaptation during mission with private psychological conference, • Post-flight debriefs		
Specific projected countermeasure(s) or mitigation(s)	• Monitoring & early detection of adaptation problems [CRL 3] • Predictive model of adaptability to long-duration missions [CRL 1] • Individual and team selection for long-duration missions [CRL 3] • Development of individual performance enhancement plan for each crewmember [CRL 1]		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Red	Yellow	Red
Justification/Rationale for Risk	Moderate likelihood/high consequence risk with low risk mitigation status; Need to reduce probability of human error, performance and/or mission failure. Serious interpersonal conflicts have occurred in space flight. The failure of flight crews to cooperate and work effectively with each other or with flight controllers has been a periodic problem in both US and Russian space flight programs. Interpersonal distrust, dislike, misunderstanding and poor communication have led to potentially dangerous situations, such as crewmembers refusing to speak to one another during critical operations, or withdrawing from voice communications with ground controllers. Such problems of group cohesiveness have a high likelihood of occurrence in prolonged space flight and if not mitigated through prevention or intervention, they will pose grave risks to the mission. Lack of adequate personnel selection, team assembly, or training has been found to have deleterious effects on work performance in organizational research studies.		
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
27a.	What are the fundamental behavioral and social stressors during long-duration missions that will most likely affect crew performance, both individual and team and how can they be tested in Earth analogue environments, to be eliminated or accommodated? [ISS 1, Moon 1, Mars 1]		
27b.	What factors contribute to the breakdown of individual and team performance and team coordination with mission support with regard to scheduling, prioritization of work activities and control of timelines? [ISS 1, Moon 1, Mars 1]		

27c.	What behaviors, experiences, personality traits and leadership styles in crewmembers most contribute to optimal performance? How are these factors related to performance of individuals and teams? [ISS 2, Moon 2, Mars 2]
27d.	What criteria can be identified during the selection process and be used to select and assemble the best teams for long-duration missions? [ISS 2, Moon 2, Mars 2]
27e.	What factors in crew design, composition, dynamics and size will best enhance the crew's ability to live and work in the space environment? How are these factors different from shorter duration missions? [ISS 2, Moon 2, Mars 2]
27f.	How can attitudes and behaviors of agency management, ground controllers, crewmembers and their families be modified to maintain and improve individual and group performance? [ISS 2, Moon 2, Mars 2]
Related Risks (by Risk Number)	SHFE risks; TBD
Important References	Connors, M.M., Harrison, A.A. and Faren, R.A. Living Aloft: Human requirements for extended space flight. NASA SP-483, Washington, D.C., National Aeronautics and Space Administration, 1985
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	Wood, J. A., Lugg, D. J., Hysong, S. J., Eksuzian, D. J., & Harm, D. L. (1999). Psychological changes in hundred-day remote Antarctic field groups. *Environment and Behavior, 31*(3), 299-337.

Risk Title: Human Performance Failure Due to Neurobehavioral Problems

Primary Risk Area	Human Behavior and Performance		
Risk Number	28		
Risk description	Human performance failure during missions due to such conditions as depression, anxiety, trauma, or other neuropsychiatric, cognitive problems		
Context/Risk Factors	Prolonged isolation and confinement; concern about health or loss of life or mission failure; loneliness and worry about family; trauma from unexpected event; differential vulnerability to neurobehavioral problems; duration of flight, crowdedness, radiation exposure, immunodeficiency issues, nutrition, neurovestibular problems, clinical capabilities, environmental health		
Specific current countermeasure(s) or mitigation(s)	1.Select-in and select-out criteria; 2.Medication therapy, including during space flight on-board; 3. Detection at the time of failure; 4. Opportunity for crewmember to communicate with crew medical officer or health provider on ground; 5. Emergency response protocol on orbit; 6. Crew medical officer behavioral medicine training pre-flight; 7. Individual pre-flight evaluations; 8. Individual pre-flight and post-flight evaluations; 9. Self-report monitoring during mission with private psychological conference; 10. Self monitoring of cognition on orbit and post-flight.		
Specific projected countermeasure(s) or mitigation(s)	• Improved capability for remote diagnosis [CRL 3] • On-board unobtrusive technologies as astronaut aids for valid detection of stress reactions and cognitive or emotional problems [CRL3] • On-board information technologies as astronaut aids for management of stress reactions and cognitive or emotional problems [CRL 3] • On-board modalities of therapy [CRL 4] • Predictive model for risk of neurobehavioral illness in-flight [CRL 3] • Individualized treatment algorithm developed pre-flight [CRL 5] • Greater interaction and observation by behavioral specialist during astronaut professional training [CRL 4] • Updated behavioral medicine aeromedical standards [CRL 4] • Self monitoring of mood pre-flight, in-flight and post-flight [CRL 4] • Improved diagnostic cognitive self-assessment [CRL 3] • Improved ability to safely and effectively manage an uncooperative crewmember during mission [CRL 3]		
Design Reference Missions	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Red	Yellow	Red
Justification/Rationale for Risk	Although infrequent, serious neurobehavioral problems involving stress and depression have occurred in space flight, especially during long-duration missions. In some of these instances, the distress has contributed to performance errors during critical operations, such as the collision of Progress into Mir during manual docking. In other instances, emotional problems led to changes in motivation, diet, sleep and exercise—all critical to behavioral and physical health in-flight. No matter how prepared crews are for long-duration flights, the US and Russian experiences reveal that at least some subset of astronauts will experience problems with their behavioral health, which will negatively affect their performance and reliability, posing risks both to individual crewmembers and to the mission. The IOM report, *Safe Passages*, notes that Earth analogue studies show an incidence rate ranging from 3 – 13 percent per person per year. The report transposes these figures to 6-7 person crew on a 3-year mission to determine that there is a not insignificant likelihood of psychiatric problems emerging (p.106).		
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
28a.	What are the best select-out tools of astronaut candidates and best select-out tools for selection of individuals to teams for specific missions to avoid possible neuropsychiatric and psychological incompatibility with the mission and fellow team members? [ISS 1, Moon 1, Mars 1]		

28b.	What are the long-term effects of exposure to the space environment (microgravity, isolation, stress) on human neurocognitive and neurobiological functions (from cellular to behavioral levels of the nervous system)? [ISS 2, Moon 2, Mars 2]
28c.	What are the long-term effects of exposure to the space environment on human emotion and psychological responses, including emotional reactivity, stress responses, long-term modulation of mood and vulnerability to affective and cognitive disorders? [ISS 3, Moon 3, Mars 3]
28d.	What objective techniques and technologies validly and reliably identify when astronauts are experiencing distress that compromises their performance capability in space? [ISS 1, Moon 1, Mars 1]
28e.	What are the best behavioral, technological and pharmacological countermeasures for managing cognitive dysfunction, neuropsychiatric and behavior problems in space? [ISS 3, Moon 3, Mars 3]
28f.	What are the best behavioral, psychological, technological and pharmacological countermeasures for managing emotional and stress-related problems in space? [ISS 3, Moon 3, Mars 3]
28g.	What are the best techniques and technologies for identification and treatment of cognitive disorders, neuropsychiatric and behavior problems in space? [ISS 4, Moon 4, Mars 4]
Related Risks (by Risk Number)	SHFE risks; TBD
Important References	Kanas, N.: Psychiatric issues affecting long-duration space missions. *Aviation Space & Environmental Medicine* 69:1211-1216, 1998.
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	Newkirk, D.: *Almanac of Soviet Manned Space flight*, Houston, TX, Gulf Publishing, 1990

Risk Title: Mismatch Between Crew Cognitive Capabilities and Task Demands

Primary Risk Area	Space Human Factors Engineering (SHFE)		
Risk Number	29		
Risk description	Human performance failure due to inadequate accommodation of human cognitive limitations and capabilities. If human cognitive performance capabilities are surpassed due to inadequate design of tools, interfaces, tasks or information support systems, mission failure or decreased effectiveness or efficiency may result. Identifying, locating, processing, or evaluating information to make decisions and perform critical tasks in short time-frames in nominal and emergency situations, with limited crew size, relying on strictly local resources is extremely subject to human error.		
Context/Risk Factors	Risk is increased by mission duration, by required levels of autonomy, by communications lags and blackouts. Time since training, time since last performing a task and level of support available from mission control on Earth are major factors that increase the probability of human error. Very long crew return times requiring a 'stand and fight' response to any malfunction on the lunar or Martian surface are expected to increases the likelihood and severity of consequences of error due to forgetting knowledge, losing skills, or failing to find information and training materials in databases.		
Specific current countermeasure(s) or mitigation(s)	Mission Control provides training, information, procedures, etc. as required to support crew actions and decision-making. Crewmembers absorb task and schedule impacts; crew resilience is the countermeasure for schedule and interface problems. There is inadequate data to enable developing realistic workloads and schedules for tasks to be performed in space contexts		
Specific projected countermeasure(s) or mitigation(s)	Tools for enabling crew autonomy with respect to information retrieval [TRL 2] Tools for analyzing tasks to identify critical skills and knowledge; tools to enable self-assessment of readiness to perform; onboard training systems that enable successful readiness to perform. [TRL 2] Design requirements for communications systems among crewmembers, between crew and mission control and among crew and intelligent agents that reduce risk of mission failure [TRL 2]		
Design Reference Missions	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Yellow	Yellow	Red
Justification/Rationale for Risk	Crews require refresher training and information support systems for numerous tasks during 6 month missions. (Ev. Level 4) Psychological literature documents increases in error with time since learning and decreases in error with *correctly* practicing the task. (Evidence level 1) Failure to correctly follow procedures has leads to fatal accidents in commercial aviation, even with greatly over learned tasks. (NTSB Reports-Level 2?)		
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
29a.	What crew size and composition is required to provide the amount of information, variety of skills, etc. required to accomplish the design reference mission? [ISS 2, Moon 1, Mars 1]		
29b.	What is required to counteract the negative effects of communications lags on human performance? [ISS 1, Moon 1, Mars 1]		
29c.	What information systems, interface designs, intelligent systems and other tools to enable autonomy are required to enable human performance to be maintained at an acceptable level over the design reference missions (Shared – Integrated Testing supports)? [ISS 2, Moon 1, Mars 1]		
29d.	What types and techniques of training are required and within what timeframes, to enable the crewmembers to accomplish the mission with increased effectiveness, efficiency and safety? [ISS 1, Moon 1, Mars 1]		

29e.	What principles of task design, procedures, job aids and tools and equipment, are required to enable crewmembers to accomplish nominal and emergency perceptual and cognitive tasks? ISS 2, Moon 1, Mars 1]
29f.	How can crewmembers and ground support personnel detect and compensate for decreased cognitive readiness to perform? [ISS 1, Moon 1, Mars 1]
29g.	What scheduling constraints are required to reduce the risk of human error due to fatigue? (Share with Sleep and Circadian Rhythm) [ISS 2, Moon 2, Mars 2]
29h.	What tools and techniques will maintain the crew's situational awareness at a level sufficient to perform nominal and emergency tasks? [ISS 2, Moon 1, Mars 1]
29i.	What characteristics of equipment, tool and computer displays; instructions, procedures, labels and warning; and human-computer interaction designs will maintain critical sensory and cognitive capabilities? [ISS 2, Moon 2, Mars 2]
29j.	What approaches to human computer interactions will maintain crew critical capabilities to assess, control and communicate? [ISS 2, Moon 2, Mars 2]
29k.	What decision-support systems are required to aid crew decision-making ? [ISS 2, Moon 2, Mars 2]
29l.	What design considerations are needed to accommodate effects of changes in gravity on perception (Launch, lunar landing, lunar launch, Earth return)? [ISS N/A, Moon 1, Mars 1]
Related Risks	No Integrated Testing Results in Technical Risks
Important References	*Human Space flight: Mission Analysis and Design*, eds. W.J. Larson, L.K. Pranke. McGraw Hill Space Technology Series. 1999.
	"Collision In Space", S. R. Ellis. *Ergonomics in Design,* Winter, 2000, pp. 4-9.
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	Woolford, B., Hudy, C. E., Whitmore, M., Berman, A., Maida, J. and Pandya, A. (2002). In Situ Training Project: LMLSTP Phase III Report. In Lane, H.W., Sauer, R.L. and Feeback, D.L. (Eds.), *ISOLATION: NASA Experiments in Closed Environment Living. Advanced Human Life Support Enclosed System Final Report*. San Diego, CA: American Astronautical Society.

Risk Title: Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems

Primary Risk Area	Human Performance, Sleep and Chronobiology		
Risk Number	30		
Risk description	Human performance failure due to disruption of circadian phase, amplitude, period, or entrainment and/or human performance failure due to acute or chronic degradation of sleep quality or quantity		
Context/Risk Factors	Work shift and sleep schedules; artificial and transmitted ambient light exposure; individual differences in vulnerability to sleep loss and circadian dynamics		
Specific current countermeasure(s) or mitigation(s)	1. Bright light entrainment pre-flight (only prior to launch), 2. Medications, 3. Scheduling constraints in Ground Rules & Constraints document, 4. Self report monitoring during mission with personal physician conference, 5. Individual active noise cancellation at sleep,		
Specific projected countermeasure(s) or mitigation(s)	1. Model of performance deficit based on sleep and circadian data (CRL 6), 2. Sleep/circadian rhythm adjustment tools pre- in- and post-flight (e.g., photic (CRL 7), nonphotic (CRL 5) and pharmacological (CRL 5/6) interventions), 3. Ability to monitor sleep, circadian and lighting parameters unobtrusively in order to predict physiological and behavioral responses (CRL 7), 4. Develop flight rule limits on critical operations during sleep period (CRL 4), 5. Personal lighting device (e.g., light visor) (CRL 6)		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Green	Green	Yellow
Justification/Rationale for Risk	High likelihood/high consequence risk with high risk mitigation status; Need to reduce probability of human error, performance and/or mission failure. Loss of circadian entrainment to Earth-based light-dark cycles and chronic reduction of sleep duration in space result in fatigue and jeopardize astronaut performance. Fatigue is a common symptom in prolonged space flight and every study of sleep in space, including those on US, Russian and European astronauts, has found that daily sleep is reduced to an average of 6 hours and even less when critical operations occur such as during nighttime Shuttle docking on ISS or during an emergency (e.g., equipment failure). Astronaut sleep in space is also physiologically altered and the most frequent medications taken in-flight by astronauts are hypnotics for sleep disturbances. Extensive ground-based scientific evidence documents that circadian disruptions and restriction of sleep at levels commonly experienced by astronauts can severely diminish cognitive performance capability, posing risks to individual astronaut safety and mission success.		
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
30a.	What are the acute and long-term effects of exposure to the space environment on biological rhythmicity on sleep architecture, quantity and quality and their relationship to performance capability? [ISS 1, Moon 1, Mars 1]		
30b.	Which countermeasures or combination of behavioral and physiological countermeasures will optimally mitigate specific performance problems associated with sleep loss and circadian disturbances during the design reference missions? [ISS 1, Moon 1, Mars 1]		
30c.	What are the long-term effects of countermeasures employed to mitigate pre, - in- and post-flight performance problems with sleep loss and circadian disturbances? [ISS 3, Moon 4, Mars 2]		
30d.	What are the best methods for in-flight monitoring of the status of sleep, circadian functioning and light exposures for assessing the effects of sleep loss and circadian dysrhythmia on performance capability that are also portable and non-intrusive in the space flight environment? (e.g., actigraphy) [ISS 2, Moon 2, Mars 2]		

30e.	What work, workload and sleep schedule(s) will best enhance crew performance and mitigate adverse effects of the space environment? [ISS 1, Moon 1, Mars 1]
30f.	What individual biological and behavioral characteristics will best predict successful adaptation to long-term space flight of sleep, circadian physiology and the neurobehavioral performance functions they regulate? [ISS 4, Moon 5, Mars 1]
30g.	(1)What mathematical and computational models should be used to predict performance associated with sleep-wake, schedule, work history, light exposure and circadian rhythm status and also provide guidelines for successful countermeasure strategies? [ISS 1, Moon 1, Mars 1]
Related Risks (by Risk Number)	TBD
Important References	Santy, P, H Kapanka, J Davis and D Stewart. Analysis of sleep on Shuttle missions. *Aviat. Space Environ. Med.* 59: 1094-1097, 1988.
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Radiation

Risk Title: Carcinogenesis

Primary Risk Area	Radiation		
Risk Number	31		
Risk Description	Unacceptable levels of increased cancer morbidity or mortality risk in astronauts caused by occupational radiation exposure or the combined effects of radiation and other space flight factors. These risks would be expressed following the mission (late).		
Context/Risk Factors	Radiation (space, medical diagnostic, atmospheric, experimental and nuclear sources including propulsion systems) and synergistic effects of radiation with other space flight factors including stress, physiological changes and microgravity.		
Specific current countermeasure(s) or mitigation(s)	Polyethylene shielding		
Specific projected countermeasure(s) or mitigation(s)	Hydrogenous shielding (TRL-5), anti-oxidants (CRL-1), pharmaceuticals (CRL-1) Gene therapy (CRL-1)		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Yellow	Red	Red
Justification/Rationale for Risk	Crew Health and Performance Post-Mission		
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
31a.	What are the probabilities for increased carcinogenesis from space radiation as a function of NASA's operational parameters (age at exposure, age, latency, gender, tissue, mission, radiation quality, dose rate and exposure protraction)? [ISS 1, Moon 1, Mars 1]		
31b.	How can tissue specific probabilities for increased carcinogenesis risk from space radiation be best evaluated and what molecular, genetic, epigenetic and abscopal (effect that irradiation of a tissue has on remote non-irradiated tissue) or other factors contribute to the tissue specificity of carcinogenic risk? [ISS 1, Moon 1, Mars 1		
31c.	How can the individual's sensitivity to radiation carcinogenesis be estimated? [ISS 2, Moon 2, Mars 1]		
31d.	How can effective biomarkers of carcinogenic risk from space radiation be developed and validated? [ISS 3, Moon 3, Mars 2]		
31e.	What are the most effective biomedical or dietary countermeasures to mitigate cancer risks? By what mechanisms are the countermeasures expected to work and do they have the same efficiency for low- and high-LET radiation? [ISS 3, Moon 3, Mars 1]		
31f.	How can animal models (including transgenics) of carcinogenesis be developed to improve estimates of cancers from space radiation and what longitudinal studies are needed? [ISS 2, Moon 2, Mars 1]		
31g.	What improvements can be made to quantitative procedures or theoretical models in order to extrapolate molecular, cellular, or animal results to determine the risks of specific cancers in astronauts? How can human epidemiology data best support these procedures or models? [ISS 3, Moon 3, Mars 2]		
31h.	Are there significant combined effects from other space flight factors (microgravity, stress, altered circadian rhythms, changes in immune responses, etc.) that modify the carcinogenic risk from space radiation? [ISS 5, Moon 5, Mars 3]		

31i.	What are the probabilities that space radiation will produce damage at specific sites on DNA including clustered DNA damage? [ISS 3, Moon 3, Mars 2]
31j.	What mechanisms modulate radiation damage at the molecular level (e.g., repair, errors in repair, signal transduction, gene amplification, bystander effects, tissue microenvironment, etc.) that significantly impact the risk of cancers and how can the understanding of mechanisms be used to predict carcinogenic risks from space radiation? [ISS 2, Moon 2, Mars 1]
31k.	What space validation experiments could improve estimates of carcinogenic risks for long-term deep-space missions? [ISS 5, Moon 5, Mars 3]
31l.	What are the most effective shielding approaches to mitigate cancer risks? [ISS 1, Moon 1, Mars 1]
31m.	What new materials or active shielding methods can be used for reducing space radiation cancer risks? [ISS 1, Moon 1, Mars 1]
Related Risks (by Risk Number)	TBD
Important References	Boice, J.D., et al., Radiation Dose and Leukemia Risk in Patients Treated for Cancer of the Cervix. J. National Cancer Institute 79, 1295-1311, 1994.
	Thompson, D.E., Cancer Incidence in Atomic Bomb Survivors. Part II: Solid tumors, 1958-1987. Radiation Research S17-S67, 1994.
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Risk Title: Acute and Late CNS Risks (Behavior, Motor Function, Etc. and Late Degenerative)

Primary Risk Area	Radiation		
Risk Number	32		
Risk Description	Damage to the central nervous system (CNS) leading to unacceptable levels of risk for changes in motor function and behavior, or neurological disorders caused by occupational radiation exposure or the combined effects of radiation and other space flight factors. These risks can be manifested during an extended mission (acute), or following return to Earth (late).		
Context/Risk Factors	Radiation (space, medical diagnostic, atmospheric, experimental and nuclear sources including propulsion systems) and synergistic effects of radiation with other space flight factors including stress, physiological changes and microgravity.		
Specific current countermeasure(s) or mitigation(s)	Polyethylene shielding		
Specific projected countermeasure(s) or mitigation(s)	Hydrogenous shielding (TRL-5), anti-oxidants (CRL-1), pharmaceuticals (CRL-1), gene therapy (CRL-1)		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Yellow	Yellow	Red
Justification/Rationale for Risk	Crew Health and Performance In-Flight and Post-Mission		
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
32a.	Is there a significant probability that space radiation would lead to immediate or acute functional changes in the CNS due to a long-term space mission and if so what are the mechanisms of change? [ISS 3, Moon 3, Mars 1]		
32b.	Is there a significant probability that space radiation exposures would lead to long-term or late degenerative CNS risks? If so what are the mechanisms of change? [ISS 3, Moon 3, Mars 1]		
32c.	How does individual susceptibility including hereditary pre-disposition (Alzheimer's, Parkinson's, apoE) and prior CNS injury (concussion or other) alter significant CNS risks? [ISS 3, Moon 3, Mars 1]		
32d.	What are the most effective biomedical or dietary countermeasures to mitigate CNS risks? By what mechanisms do the countermeasures work? [ISS 4, Moon 4, Mars 1]		
32e.	How can animal models of CNS risks, including altered motor and cognitive function, behavioral changes and late degenerative risks be best used for estimating space radiation risks to astronauts? [ISS 4, Moon 3, Mars 1]		
32f.	Are there significant CNS risks from combined space radiation and other physiological or space flight factors (e.g., bone loss, microgravity, immune-endocrine systems or other)? [ISS 5, Moon 5, Mars 3]		
32g.	What are the molecular, cellular and tissue mechanisms of damage (DNA damage processing, oxidative damage, cell loss through apoptosis or necrosis, changes in the extra-cellular matrix, cytokine activation, inflammation, changes in plasticity, micro-lesion (clusters of damaged cells along heavy ion track, etc.) in the CNS? [ISS 4, Moon 3, Mars 1]		
32h.	What are the different roles of neural cell populations, including neuronal stem cells and their integrative mechanisms in the morphological and functional consequences of space radiation exposure? [ISS 2, Moon 2, Mars 1]		
32i.	Are there biomarkers for detecting damage or susceptibility to/for radiation-induced CNS damage? [ISS 4, Moon 3, Mars 2]		

32j.	What quantitative procedures or theoretical models are needed to extrapolate molecular, cellular, or animal results to predict CNS risks in astronauts? How can human epidemiology data best support these procedures or models? [ISS 4, Moon 3, Mars 2]
32k.	What are the most effective shielding approaches to mitigate CNS risks? [ISS 1, Moon 1, Mars 1]]
32l.	What space validation experiments could improve estimates of CNS risks for long-term deep-space missions? [ISS 5, Moon 5, Mars 3]
Related Risks (by Risk Number)	TBD
Important References	National Academy of Sciences Space Science Board, HZE Particle Effects in Manned Space flight, National Academy of Sciences U.S.A. Washington D.C., 1973.
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Risk Title: Other Degenerative Tissue Risks

Primary Risk Area	Radiation		
Risk Number	33		
Risk Description	Unacceptable levels of morbidity or mortality risks for degenerative tissue diseases (non-cancer or non-CNS) such as cardiac, circulatory or digestive diseases or cataracts caused by occupational radiation exposure or the combined effects of radiation and other space flight factors.		
Context/Risk Factors	Radiation (space, medical diagnostic, atmospheric, experimental and nuclear sources including propulsion systems) and synergistic effects of radiation with other space flight factors including stress, physiological changes and microgravity.		
Specific current countermeasure(s) or mitigation(s)	Polyethylene shielding		
Specific projected countermeasure(s) or mitigation(s)	Hydrogenous shielding (TRL-5), anti-oxidants (CRL-1), pharmaceuticals (CRL-1), gene therapy (CRL-1)		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Yellow	Yellow	Red
Justification/Rationale for Risk	Crew Health and Performance Post-Mission		
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
33a.	What are the probabilities for degenerative tissue risks from protons and HZE ions as a function of NASA's operational parameters (age at exposure, age and time after exposure, gender, tissue, mission, radiation quality, dose rate)? [ISS 2, Moon 2, Mars 1]		
33b.	What are the mechanisms of degenerative tissues risks in the heart, circulatory, endocrine, digestive, lens and other tissue systems? [ISS 2, Moon 2, Mars 1]		
33c.	How can the latency period for degenerative tissue risks, including sub-clinical diseases, following space radiation exposures be estimated? [ISS 3, Moon 3, Mars 1]		
33d.	What are the most effective biomedical or dietary countermeasures to degenerative tissue risks? By what mechanisms do the countermeasures work? [ISS 3, Moon 3, Mars 1]		
33e.	What quantitative procedures or theoretical models are needed to extrapolate molecular, cellular, or animal results to predict degenerative tissue risks in astronauts? How can human epidemiology data best support these procedures or models? [ISS 4, Moon 4, Mars 2]		
Related Risks (by Risk Number)	TBD		
Important References	Preston, D.L., et al., Studies of Mortality of Atomic Bomb Survivors Report 13: Solid Cancer and Non-cancer disease mortality: 1950-1997. Radiation Research 160, 381-407, 2003.		
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	Cucinotta, F.A., Manuel, F., Jones, J., Izsard, G., Murray, J., Djojonegoro, B. and Wear, M., Space Radiation and Cataracts in Astronauts. Radiation Research 156, 460-466, 2001.
	National Council on Radiation Protection and Measurements, Recommendations of Dose Limits for Low Earth Orbit. NCRP Report 132, Bethesda MD, 2000.
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Risk Title: Heredity, Fertility and Sterility Risks

Primary Risk Area	Radiation		
Risk Number	34		
Risk Description	Unacceptable levels of increased hereditary, fertility, or sterility risk caused by occupational radiation exposure or the combined effects of radiation and other space flight factors. These decrements can be following return to Earth (late), or in the progeny of astronauts (for hereditary risks).		
Context/Risk Factors	Radiation (space, medical diagnostic, atmospheric, experimental and nuclear sources including propulsion systems) and synergistic effects of radiation with other space flight factors including stress, physiological changes and microgravity.		
Specific current countermeasure(s) or mitigation(s)	Polyethylene shielding, family counseling		
Specific projected countermeasure(s) or mitigation(s)	Hydrogenous shielding (TRL-5), anti-oxidants (CRL-1), pharmaceuticals (CRL-1), gene therapy (CRL-1)		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Green	Green	Yellow
Justification/Rationale for Risk	Crew Health and Performance Post-Mission		
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
34a.	What are the risks of hereditary, fertility or sterility effects as a result of exposure to space radiation? [ISS 4, Moon 3, Mars 2]		
34b.	Is there a transmissible risk for neurodegenerative or other non-cancer/non-CNS diseases to the offspring of those exposed to radiation? [ISS 3, Moon 3, Mars 3]		

Related Risks (by Risk Number)	TBD
Important References	National Academy of Sciences Space Science Board, Report of the Task Group on the Biological Effects of Space Radiation. Radiation Hazards to Crews on Interplanetary Mission National Academy of Sciences, Washington, D.C., 1997.
	National Council on Radiation Protection and Measurements, Recommendations of Dose Limits for Low Earth Orbit. NCRP Report 132, Bethesda MD, 2000.
	Bryn A. Bridges, Radiation and Germline Mutation at Repeat Sequences: Are We in the Middle of a Paradigm Shift? Radiation Research 156, 631-641, 2001.
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	Schull, W.J., Otake, M. and Neel, J.V., Genetic Effects of the Atomic Bombs: A Reappraisal. Science 213, 1220-1227, 1981.

Risk Title: Acute Radiation Syndromes

Primary Risk Area	Radiation		
Risk Number	35		
Risk Description	Any increased risk of clinically significant acute radiation syndromes caused by occupational radiation exposure or the combined effects of radiation and other space flight factors. These decrements can be manifested during an extended mission (acute), or following return to Earth (late)		
Context/Risk Factors	Radiation (space, medical diagnostic, atmospheric, experimental and nuclear sources including propulsion systems) and synergistic effects of radiation with other space flight factors including stress, physiological changes and microgravity.		
Specific current countermeasure(s) or mitigation(s)	Polyethylene shielding		
Specific projected countermeasure(s) or mitigation(s)	Hydrogenous shielding (TRL-5), anti-oxidants (CRL-1), pharmaceuticals (CRL-1), gene therapy or bone marrow transplant (CRL-1)		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Green	Red	Red
Justification/Rationale for Risk	Crew Health and Performance In-Flight and Crew Health and Performance Post-Mission	Crew Health and Performance Post-Mission	Crew Health and Performance Post-Mission

Enabling Questions [Priority on scale of 1 (high) to 5 (low)]	
35a.	How can predictions of acute space radiation events be improved? [ISS 4, Moon 2, Mars 2]
35b.	Are there synergistic effects arising from other space flight factors (microgravity, stress, immune status, bone loss, damage to intestinal cells reducing their ability to absorb medication? etc.) that modify acute risks from space radiation including modifying thresholds for such effects? [ISS 5, Moon 3, Mars 3]
35c.	What are the molecular, cellular and tissue mechanisms of acute radiation damage (DNA damage processing, oxidative damage, cell loss through apoptosis or necrosis, cytokine activation, etc.)? [ISS 4, Moon 3, Mars 3]
35d.	Does protracted exposure to space radiation modify acute doses from SPEs in relationship to acute radiation syndromes? [ISS 4, Moon 3, Mars 3]
35e.	What are the most effective biomedical or dietary countermeasures to mitigate acute radiation risks? By what mechanisms do the countermeasures work? [ISS 4, Moon 3, Mars 3]
35f.	What quantitative procedures or theoretical models are needed to extrapolate molecular, cellular, or animal results to predict acute radiation risks in astronauts? How can human epidemiology data best support these procedures or models? [ISS 4, Moon 3, Mars 3]
35g.	What are the most effective shielding approaches to mitigate acute radiation risks? [ISS 1, Moon 1, Mars 1]
Related Risks (by Risk Number)	TBD
Important References	National Council on Radiation Protection and Measurements, Recommendations of Dose Limits for Low Earth Orbit. NCRP Report 132, Bethesda MD, 2000.
	National Council on Radiation Protection and Measurements, NCRP. Guidance on Radiation Received in Space Activities, NCRP Report 98, NCRP, Bethesda (MD), 1989.
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Advanced Human Support Technology

Risk Title: Monitor Air Quality

Primary Risk Area	Advanced Environmental Monitoring and Control (AEMC)		
Risk Number	36		
Risk Description	Chemical detection in the crew atmosphere, or elsewhere in the air processing system, can indicate the buildup of hazardous chemicals, pre-combustion reaction products, malfunction of life support equipment, or other hazardous event such as accidental release from an experiment. Lack of timely information about the presence of such indicators can lead to delayed response by the crew or by automated response equipment, leading in turn to hazard to the crew.		
Context/Risk Factors	Malfunction in life support system which may be gradual or sudden; accidental event such as fire or leak		
Specific current countermeasure(s) or mitigation(s)	Volatile Organic Analyzer (currently not functioning), Compound Specific Combustion Product Analyzer, Major Constituent Analyzer (currently not functioning). Ground analysis of returned samples. Crew indicators such as reports of odor, nausea.		
Specific projected countermeasure(s) or mitigation(s)	Highly sensitive somewhat slower analyzer suite [TRL 4] Distributed network of rapid, smaller detectors [TRL 4]		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Yellow	Red	Red
Justification/Rationale for Risk	The time constant for measurement varies widely depending on the cause. Gradual buildup of toxic chemicals may take months, calling for highly sensitive detection at slow intervals, perhaps daily. Leakage or pre-combustion events are expected to occur more rapidly, requiring more rapid detection (minutes), though less sensitive detection may be necessary. Localized information is needed to identify the problem source. Existing technology for ground-based measurement is massive, power hungry and requires significant crew skill and time. No single technology currently can address all Space Maximum Allowable Concentration SMAC chemicals. Combustion in micro, lunar and Martian gravity is very different from combustion on Earth and has different pre-combustion indicators. Harmful foreign matter may be inadvertently brought in following extravehicular activity (EVA) and should be monitored prior to cabin entry as well as inside the habitat. The same monitoring technology may be useful for helping diagnose crew health by providing breath monitoring data.		
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
36a.	What technologies can be used to detect slow, gradual changes in the chemical and microbial environment (work with Environmental Health)? [ISS 1, Moon 1, Mars 1]		
36b.	What set of technologies and data can be used to make the diagnosis of potentially hazardous event from chemical data quickly (work with Environmental Health, ALS)? [ISS 1, Moon 1, Mars 1]		
36c.	How can environmental information be used to assist in-flight biomonitoring for health and performance of the astronauts (supporting Biomedical monitoring)? [ISS 3, Moon 3, Mars 3]		
36d.	What technologies must be developed to rapidly detect and address fire in space? [ISS 1, Moon 1, Mars 1]		

36e.	How can technology help make appropriate response to a hazardous event be achieved in a timely manner (needed for automated systems)? [ISS 2, Moon 2, Mars 2]
36f.	What set of technologies and data can be used to detect and diagnose hardware malfunction, in such systems as life support or in situ resource utilization by assessment of environmental (air, water, or surfaces) changes (work with ALS)? [ISS 2, Moon 2, Mars 2]
Related Risks	Inability to maintain acceptable atmosphere in habitable areas
	Inability to provide and recover potable water
	Inability to provide and maintain bioregenerative life support systems
	No Integrated Testing Results in Technical Risks
	7.13 What diagnostic and environmental monitoring laboratory technologies need to be developed for the detection and diagnosis of infectious disease in microgravity? (3)
	6.20 What are the best methods of in-flight recognition, monitoring and management of neurobehavioral dysfunction, including cognitive and performance dysfunction, emotional and stress-related dysfunction, neuropsychiatric dysfunction and social psychological dysfunction?
	11.29 What are the provisions, technologies, methods and skills necessary to support environmental health-related diagnosis and monitoring including microbiological, toxicological, noise and radiation issues?
Important References	Advanced Technology for Human Support in Space, National Research Council Report, 1997. Downloadable from http://peer1.nasaprs.com/peer_review/prog/nap.pdf
	AEMC Technology Development Requirements (1998) downloadable from http://peer1.nasaprs.com/peer_review/prog/prog.html
	NASA/JSC Toxicology Group Home Page http://www.jsc.nasa.gov/toxicology/
	"Toxicological Assessment of the International Space Station Atmosphere with Emphasis on Metox Canister Regeneration," J. James, 33rd International Conference on Environmental Systems, SAE#2003-01-2647, July 2003.
	"Cabin Air Quality Dynamics on Board the International Space Station," J. Perry, B. Peterson, 33rd International Conference on Environmental Systems, SAE#2003-01-2650, July 2003.

Risk Title: Monitor External Environment

Primary Risk Area	Advanced Environmental Monitoring and Control (AEMC)		
Risk Number	37		
Risk Description	Failure to detect hazards external to the habitat can lead to lack of remedial action, leading to hazard to the crew.		
Context/Risk Factors	TBD		
Specific current countermeasure(s) or mitigation(s)	Trace Gas Analyzer (TGA) using miniature quadrupole mass spectrometry technology.		
Specific projected countermeasure(s) or mitigation(s)	[ISS]: Second generation TGA [TRL 6]; Realtime radiation monitor [TRL 4] [Moon and Mars]: Third generation TGA to include particulate measurement [TRL 3]; Real-time radiation monitor [TRL 4]		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Yellow	Red	Red
Justification/Rationale for Risk	Possible events on ISS, Moon, or Mars include leakage of ammonia coolant, of cabin atmosphere, or of rocket propellant. The lunar or Martian environment itself may have some hazard such as the chemical composition or physical nature of the dust. It is expected that in some cases these can be readily detected during extravehicular activity (EVA).		
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
37a.	What sensors are required to monitor hazardous conditions in the extra-vehicular environment (work with AEVA)? [ISS 1, Moon 1, Mars 1]		
Related Risks	TBD		
Important References	"Trace Gas Analyzer for Extra-Vehicular Activity," T. Abbasi, M. Christensen, M. Villemarette, M. Darrach, A. Chutjian, 31st International Conference on Environmental Systems, SAE#2001-01-2405, July 2001.		

Risk Title: Monitor Water Quality

Primary Risk Area	Advanced Environmental Monitoring and Control (AEMC)		
Risk Number	38		
Risk description	Chemicals in the crew water supply, or elsewhere in the water reclamation system, can indicate buildup of hazardous organic chemicals, electrochemical reaction products, malfunction of life support equipment, or other hazardous event such as accidental release from an experiment. Microbial growth can be hazardous to crew health; microbial ecology also in indicator of the proper functioning of life support system, especially if microbial water processing is employed. Lack of timely information about the presence of such indicators can lead to delayed response by the crew or by automated response equipment, leading in turn to hazard to the crew.		
Context/Risk Factors	Malfunction in life support system which may be gradual or sudden; accidental event such as leak of ammonia from cooling system into water supply through heat exchanger		
Specific current countermeasure(s) or mitigation(s)	Water conductivity; Total Organic Carbon (currently not in use due to difficulty in bubble removal); manual plate culturing at ambient temperature with visual estimate. Ground analysis of returned samples. Crew report of odor or taste.		
Specific projected countermeasure(s) or mitigation(s)	Compact online chemical water analyzer suite [TRL 3-4]; microbial analysis instrument [TRL 3]		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Yellow	Red	Red
Justification/Rationale for Risk	The time constant for measurement varies widely depending on the cause. Gradual buildup of toxic chemicals may take months, calling for highly sensitive detection at slow intervals, perhaps daily. Leakage events are expected to occur more rapidly, requiring more rapid detection (minutes), though less sensitive detection may be necessary. Localized information is needed to identify the problem source. Existing technology for ground-based measurement is massive, power hungry, needs hazardous reagents, requires significant crew skill and time and is sensitive to micro, lunar, or Martian gravity multiphase issues.		
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
38a.	What technologies can be used to detect slow, gradual changes in the chemical and microbial environment (work with ALS and Environmental Health)? [ISS 1, Moon 1, Mars 1]		
38b.	What set of technologies and data can be used to make the diagnosis of potentially hazardous event from chemical data quickly (work with ALS and Environmental Health)? [ISS 1, Moon 1, Mars 1]		
38c.	How can technology help make appropriate response to a hazardous event be achieved in a timely manner (needed for developing automated system)? [ISS 2, Moon 2, Mars 2]		
38d.	What set of technologies and data can be used to detect and diagnose hardware malfunction by assessment of environmental (air, water, or surfaces) changes (work with ALS)? [ISS 1, Moon 1, Mars 1]		
Related Risks	Inability to maintain acceptable atmosphere in habitable areas		
	Inability to provide and recover potable water		
	Inability to provide and maintain bioregenerative life support systems		
	No Integrated Testing Results in Technical Risks		

Important References	Advanced Technology for Human Support in Space, National Research Council Report, 1997. Downloadable from http://peer1.nasaprs.com/peer_review/prog/nap.pdf
	AEMC Technology Development Requirements (1998) downloadable from http://peer1.nasaprs.com/peer_review/prog/prog.html
	NASA/JSC Toxicology Group Home Page http://www.jsc.nasa.gov/toxicology/
	"ISS Potable Water Sampling and Chemical Analysis: Expeditions 4-6," D. Plumlee, P. Mudgett, J. Schultz, J. James, 33rd International Conference on Environmental Systems, SAE#2003-01-2401, July 2003.
	Characterization and Monitoring of Microbial Species in the International Space Station Drinking Water," M. LaDuc, 33rd International Conference on Environmental Systems, SAE#2003-01-2404, July 2003.

Risk Title: Monitor Surfaces, Food and Soil

Primary Risk Area	Advanced Environmental Monitoring and Control (AEMC)		
Risk Number	39		
Risk description	This includes solid surfaces, soil (which includes solid, liquid and gas) and food. Surfaces may become contaminated by harmful chemicals or microbial growth. Complex multi-phase matrices such as soil will also need to be monitored to ensure proper growth conditions for plants. Failure to detect contamination of food supplies can lead to hazard to the crew health. Lack of timely information about the presence of such hazards can lead to delayed remedial action response by the crew or automated remedial machinery, leading in turn to hazard to the crew.		
Context/Risk Factors	Low or microgravity allows for greater accumulation of liquids on surfaces by surface tension and longer persistence of matter suspended in air, increased the likelihood of surface impact.		
Specific current countermeasure(s) or mitigation(s)	Occasional manual plate culturing of samples from swabbed surfaces.		
Specific projected countermeasure(s) or mitigation(s)	Reliable, repeatable sampling methods taking minimal crew time [TRL 2]. Detection and identification of surface contamination by optical interrogation [TRL 3].		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Yellow	Red	Red
Justification/Rationale for Risk	The area of contamination of surfaces in the space environment has received relatively little attention to date. The risk is essentially unknown.		
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
39a.	What technologies can be used to detect slow, gradual changes in the chemical and microbial surface environment? (work with Environmental Health and ALS) [ISS 1, Moon 1, Mars 1]		
39b.	What set of technologies and data can be used to make the diagnosis of potentially hazardous event involving surfaces quickly? (work with Environmental Health and Life Support) [ISS 1, Moon 1, Mars 1]		
39c.	What technologies are required to meet the radiation monitoring requirements of a mission? [ISS TBD, Moon TBD, Mars TBD]		
39d.	What sample acquisition and preparation technologies can meet the requirements of the gaseous, aqueous and solid-phase matrices monitoring? [ISS TBD, Moon TBD, Mars TBD]		

39e.	What research is required to validate design approaches for multiphase flow for monitoring systems in varying gravity environments? [ISS TBD, Moon TBD, Mars TBD]
Related Risks	Inability to maintain acceptable atmosphere in habitable areas
	Inability to provide and recover potable water
	Inability to provide and maintain bioregenerative life support systems
	No Integrated Testing Results in Technical Risks
Important References	Advanced Technology for Human Support in Space, National Research Council Report, 1997. Downloadable from http://peer1.nasaprs.com/peer_review/prog/nap.pdf
	AEMC Technology Development Requirements (1998) downloadable from http://peer1.nasaprs.com/peer_review/prog/prog.html

Risk Title: Provide Integrated Autonomous Control of Life Support Systems

Primary Risk Area	Advanced Environmental Monitoring and Control (AEMC)		
Risk Number	40		
Risk description	Lack of stable, reliable, efficient Process Control for the life support system		
Context/Risk Factors	Longer mission time such as Martian scenario means greater potential for life support system to become unstable. Decreasing life support system mass by decreasing air or water buffer sizes (an economically desirable objective) increases potential for system to become unstable.		
Specific current countermeasure(s) or mitigation(s)	Manual and low level process control		
Specific projected countermeasure(s) or mitigation(s)	Automated control of life support, integrated with monitoring system [TRL 2].		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Green	Yellow	Red
Justification/Rationale for Risk	Automated control of life support is needed to minimize the crew workload. Industrial process control technology is manufacturing-oriented (input/output) with a narrow range of time constants. Space life support is an endless loop-recycling environment, with time constants ranging from fast accidental incidents to life cycles of plant crops (months). Advances in process control technology are needed for safe, efficient control of the life support system.		
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
40a.	How do we design an effective control system with flexibility, modularity, growth potential, anti-obsolescence and accommodate varied, new, & unknown test articles, taking advantage of standards (work with Integrated Testing)? [ISS 1, Moon 1, Mars 1]		
40b.	How does a control system manage and plan for the long time constants of certain biological processes that lead to changes days, months later; and reconciles between discrete events, continuous processing and varying time constants (work with Integrated Testing)? [ISS 1, Moon 1, Mars 1]		
40c.	How do we assure that human situation awareness is at a high level when needed, while offloading the crew workload for most of the time (work with SHFE and Integrated Testing)? [ISS 2, Moon 2, Mars 2]		

40d.	How can a control system support strategic decisions; launch readiness/abort/return home decisions and procedures (work with SHFE and Integrated Testing)? [ISS 1, Moon 1, Mars 1]
40e.	How can we develop real time prognostic capabilities to predict failures before they occur and degradations before they have impact (work with ALS and Integrated Testing)? [ISS 1, Moon 1, Mars 1]
40f.	How do we allocate efficiently and safely between space-based control and ground-based control (work with SHFE and Integrated Testing)? [ISS 1, Moon 1, Mars 1]
40g.	In very large and complex systems, how can we synchronize system states across subsystems (work with Integrated Testing)? [ISS 1, Moon 1, Mars 1]
40h.	How do we trade between buffers and controls to ensure safe and reliable system (work with ALS and Integrated Testing)? [ISS 1, Moon 1, Mars 1]
40i.	How can understanding process control help determine which sensors may be missing and where sensors should be placed (work with Integrated Testing)? [ISS 1, Moon 1, Mars 1]
Related Risks	No Integrated Testing Results in Technical Risks
Important References	Final Report, Workshop on Advanced System Integration and Control for Life Support (ASICLS) Monterey Plaza Hotel , 26 – 28 August 2003, Monterey, CA
	Advanced Technology for Human Support in Space, National Research Council Report, 1997. Downloadable from http://peer1.nasaprs.com/peer_review/prog/nap.pdf
	NASA Advanced Environmental Monitoring and Control (AEMC) Program Review, Final Report, USRA, August 1999. Also, AEMC review response sent to HQ Sept 1999.
	AEMC Technology Development Requirements (1998) downloadable from http://peer1.nasaprs.com/peer_review/prog/prog.html

Risk Title: Provide Space Suits and Portable Life Support Systems

Primary Risk Area	Advanced Extravehicular Activity (AEVA)		
Risk Number	41		
Risk description	Inability to provide a robust EVA system that provides the life support resources, mobility and ancillary support including robotics interactions and airlock design to perform the defined mission EVA tasks		
Context/Risk Factors	Suit pressure, power consumption, CO_2 removal system consumption., thermal comfort consumables, increased carry weight, dust contamination, accommodation for waste including potential for emisses		
Specific current countermeasure(s) or mitigation(s)	[All missions]: Regenerable CO_2 removal systems, longer life rechargeable batteries, limited maintenance, dedicated water. [Moon and Mars]: Apollo Era dust mitigation.		
Specific projected countermeasure(s) or mitigation(s)	[All missions]: Regenerable closed loop CO_2 removal systems, longer shelf and service life batteries, increased on-orbit space suit service life, non-venting heat rejection system, cleaning and maintenance of soft goods (e.g., LCVG) [TRL TBD] [Moon and Mars]: Dust removal and dust prevention, reduced mass of suit and PLSS [TRL TBD]		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Green	Yellow	Red
Justification/Rationale for Risk	Long-duration in Martian partial Gravity leads to increased hardware use. Hardware failures could occur without the capability for equipment servicing and overhaul. Dust contamination leads to equipment failures and decreased suit mobility from contaminated bearings and joints.		
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
41a.	What EVA system design can be developed to reduce the pre-breath requirement? [ISS N/A, Moon 1, Mars 1]		
41b.	What suit and PLSS technology must be developed to meet mission requirements for EVA mobility? [ISS N/A, Moon 2, Mars 1]		
41c.	How do we protect against planetary surface dust through suit and airlock system design? [ISS N/A, Moon 1, Mars 1]		
41d.	How do we protect against toxic fluids and contaminants? [ISS 2, Moon 2, Mars 2]		
41e.	How do we design space suits to fit multiple crewmembers of various sizes and shapes? [ISS 1, Moon 1, Mars 1]		
41f.	How do we improve glove dexterity? [ISS 1, Moon 1, Mars 1]		
41g.	What technologies can be developed to provide passive or active thermal insulation in various environments, including deep-space and lunar vacuum? [ISS N/A, Moon 1, Mars 1]		
41h.	What technologies must be developed to meet mission non-venting and non-contaminating requirements? [ISS N/A, Moon 2, Mars 2]		
41i.	How do we provide and manage increased information to EVA crewmember, including suit parameters, systems status, caution and warning, video, sensor data, procedures and text and graphics? [ISS N/A, Moon 2, Mars 2]		
41j.	How do we achieve EVA and robotic interaction and cooperation? [ISS N/A, Moon 1, Mars 1]		
41k.	What biomedical sensors are needed to enhance safety and performance during EVAs? [ISS N/A, Moon 2, Mars 2]		
41l.	How can space suit design accommodate crewmember physical changes after long time in microgravity? [ISS N/A, Moon 1, Mars 1]		
41m.	What technology can be developed to monitor EVA crewmember thermal status and provide auto-thermal control? [ISS N/A, Moon 1, Mars 1]		
41n.	Can a practical EMU containment receptacle for emesis be developed? If a vomiting episode occurs, is there a way of refurbishing the suit during the mission? How can suit life support systems be designed to be more resistant to vomiting episode? [ISS 1, Moon 1, Mars 1]		

Related Risks	(AEMC3) Hazardous Event Monitoring, (AEMC4) Life Support System monitoring,(AIM5) Lack of Key Expertise, (AIM6) Systems & Operations Designs not Efficient, (AIM7) Unforeseen Consequences of Interactions, 2 (ALS) Inability to provider and recover potable water, (SHFE1) Human performance failure due to inadequate accommodation of human physical limitations and requirements, (SHFE2) Human performance failure due to inadequate accommodation of human cognitive limitations and capabilities, (SHFE3) Mission failure due to failures in collaboration and teamwork among intelligent agents.
Important References	Advanced Technology for Human Support in Space, Committee on Advanced Technology for Human Support in Space, Aeronautics and Space Engineering Board, National Research Council, National Academy Press, Washington DC, 1997.

Risk Title: Maintain Food Quantity and Quality

Primary Risk Area	Advanced Food Technology (AFT)		
Risk Number	42		
Risk description	If the food system is inadequate for the mission, then crew nutritional requirements may not be met and crew health and performance will suffer. An inadequate food system is one that is unsafe or provides food that fails to meet nutritional requirements or is unacceptable from a sensory standpoint.		
Context/Risk Factors	Inadequate storage conditions and environmental control, inadequate shelf life, inadequate food packaging, product formulation, undefined nutritional requirements, below standard food intakes, chemical or microbial contamination of food, inadequate food processing/preservation, inadequate quantity of food, inadequate variety, crew psychological and physiological changes, and elevated stress and boredom.		
Specific current countermeasure(s) or mitigation(s)	Menu developed based on daily nutritional requirements, vitamin D supplementation, hazard analysis critical control point processing, testing and evaluation, increased menu cycle, increased variety of menu items.		
Specific projected countermeasure(s) or mitigation(s)	• Enhanced food system with increased variety and acceptability [TRL 4] • Assessment of food psychosocial importance [TRL 2] • Refined nutritional requirements [TRL 4] • Development of extended shelf life food through improved food preservation technologies [TRL 2] • High barrier and low mass food packaging materials [TRL 2] • Hazard analysis critical control point processing [TRL 4] • Determine effects of radiation on food [TRL 1]		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Yellow	Green	Red
Justification/ Rationale for Risk	Food provides the crew with the required nutritional daily intake. In addition, food through its variety and acceptability provides a psychosocial component by decreasing stress during a mission. An inadequate food supply will lead to unhealthy crewmembers hence resulting in a compromised mission through reduced crew performance.		

Enabling Questions [Priority on scale of 1(high) to 5 (low)]	
42a.	What procedures (e.g., storage, processing, preparation, clean-up), such as HACCP, need to be developed to assure a safe food system? [ISS 1, Moon 1, Mars 1]
42b.	What are the allowable limits of microbial and chemical contamination in the food? [ISS 1, Moon 1, Mars 1]
42c.	How does space radiation affect the functionality and nutritional content of the stored staple ingredients for food processing? [ISS N/A, Moon 1, Mars 1]
42d.	What food processing technologies are required when using stored staple ingredients to ensure a food system that is nutritious, safe and acceptable? [ISS N/A, Moon 1, Mars 1]
42e.	What food packaging materials will provide the physical and chemical attributes, including barrier properties, to protect the food from the outside environment and assure the 3-5 year shelf life? [ISS 1, Moon 1, Mars 1]
42f.	What food packaging material will be biodegradable, easily processed, or be lighter in mass than the current packaging and can still provide the physical and chemical attributes including barrier properties to protect the food from the outside environment and assure the 3-5 year shelf life? [ISS 1, Moon 1, Mars 1]
42g.	What food preservation technologies will provide prepackaged food items with a shelf life of 3-5 years? [ISS 2, Moon 2, Mars 2]
42h.	What are the impacts of reduced-G and atmospheric pressure on the food processing activities? [ISS N/A, Moon 2, Mars 1]
42i.	What are the impacts of reduced-G and atmospheric pressure on the food preparation activities? [ISS 3, Moon 2, Mars 1]
42j.	What nutritional content and sensory attributes changes (including radiation induced effects) in the prepackaged food items will occur over the shelf life of the food? [ISS 2, Moon 2, Mars 2]
42k.	What food system technology selection criteria will be used to effectively reduce critical resources such as air, water, thermal, biomass and solid waste processing, during a mission? [ISS 2, Moon 2, Mars 2]
42l.	What are the changes (taste, odor, etc.) that occur in crewmember's sensory perceptions during space flight that would affect food acceptability? [ISS 3, Moon 3, Mars 3]
42m.	What are the physical and chemical requirements for each of the stored staple ingredient items to assure effective processing into acceptable, safe and nutritious food ingredients? [ISS N/A, Moon 2, Mars 2]
42n.	What level of acceptability in the food system is required to provide psychosocial well being of the crew? [ISS 3, Moon 3, Mars 2]
42o.	What level of variety (e.g., number of food items, length of menu cycle) in the food system is required to provide psychosocial well being of the crew? [ISS 3, Moon 3, Mars 2]
42p.	What modeling techniques can be used to measure the subjective portions of the food system such as palatability, nutrition, psychological issues and variety? [ISS 3, Moon 3, Mars 2]
Related Risks	Inability to maintain acceptable atmosphere in habitable areas
	Inability to provide and recover potable water.
	Inability to provide and maintain bioregenerative life support systems
	Inability to maintain thermal balance in habitable areas
	Inability to manage waste, including collection, transport, stabilization, storage, processing and disposal
	Inadequate nutrition
	Human performance failure because of poor psychosocial adaptation.
	Allergies and hypersensitivity reactions

	Loss of skeletal muscle mass, strength, and/or endurance intensities.
	Radiation1. Carcinogenesis
	Radiation2. Acute and Late CNS Risks
	Radiation3. Degenerative Tissue Risks
	Radiation4. Acute Radiation Syndromes
	AEMC: Efficient Monitoring Solutions, Sample preparation, and data fusion
	AEMC. Lack of Timely, Chemical and Biological information in solid and multi-phase matrices
	SHFE. Mismatch between crew cognitive capabilities and task demands
	SHFE. Mis-assignment of responsibilities within multi-agent systems
	No integrated testing results in technical risks
Important References	NASA Johnson Space Center. Nutritional Requirements for International Space Station Missions Up To 360 Days. JSC-28038; 1996.
	M Perchonok, S. French, B. Swango, V. Kloeris, D. Barta, M. Lawson, J. Joshi, Advanced Food Technology Workshop Report Volume I, NASA/CP–2003–212055, 2003.
	M Perchonok, S. French, B. Swango, V. Kloeris, D. Barta, M. Lawson, J. Joshi, Advanced Food Technology Workshop Report Volume II, NASA/CP–2003–212055, 2003.
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	Isolation NASA Experiments in Closed-Environment Living Advanced Human Life Support Enclosed System Volume 104 SCIENCE AND TECHNOLOGY SERIES; A Supplement to Advances in the Astronautical Sciences Edited by: Helen W. Lane, Richard L. Sauer, and Daniel L. Feeback. Published for the American Astronautical Society by Univelt, Incorporated, P.O. Box 28130, San Diego, California 92198 web: http://lsda.jsc.nasa.gov/books/ground/chambers.pdf.
	Kerwin, J. and Seddon, Rhea. (2002). Eating in Space – From an Astronaut's Perspective. Nutrition 18 (10):913 - 920
	Perchonok, M. and Bourland, C. (2002). Food for the NASA Space Missions; Past, Present and Future. Nutrition 18 (10):921 - 925.
	Safe Passage: Astronaut Care for Exploration Missions, Board on Health Sciences Policy, Institute of Medicine, National Academy Press, Washington, DC, 2001

Risk Title: Maintain Acceptable Atmosphere

Primary Risk Area	Advanced Life Support (ALS)		
Risk Number	43		
Risk description	Inability to control atmosphere concentration CO_2 and O_2 and trace contaminants in habitable areas; excessive airborne chemical pollutants (such as formaldehyde, ethylene glycol, freon, from leaks, fires, etc.), including microbial contaminants (microbial degradation of biological wastes).		
Context/Risk Factors	Remoteness, insensitivity of control system to contaminants leading to toxic build ups due to a closed system, complexity of systems and increase in the number of systems (e.g., additional solid waste processing, plant growth, food processing, etc. for what?). Severely constrained resources (such as mass, power, volume, thermal, crew time)		
Specific current countermeasure(s) or mitigation(s)	Technology development to further close the air loop, Carbon Dioxide Reduction. This includes testing, modeling and analysis. Regenerable Trace Contaminant Control System (TCCS) development (testing, modeling). Looking at potentially more robust methods of removing CO_2 and combining functions for air management. Resupply	Development in new sorbent, application in CO_2 Moisture Removal System (CMRS) an open loop system. Model and analysis trade of technology. Regenerable Trace Contaminant Control System (TCCS). Limited resupply.	Analysis to identify projected contaminant sources from other systems. Technology development to further close the air loop, Carbon Dioxide Reduction. This includes testing, modeling and analysis. Regenerable Trace contaminant control (testing, modeling). Looking at potentially more robust methods of removing CO_2 and combining functions for air management. Compressor technology applicable also for ISRU. Extremely limited resupply
Specific projected countermeasure(s) or mitigation(s)	o Improved Carbon Dioxide Removal and Reduction System – [TRL 3, 4] o Regenerable TCCS – [TRL 4]	o Look to have better models identifying contaminant load. o CMRS – [TRL 4] o ISRU o Bioregenerative	o Improved Carbon Dioxide Removal and Reduction System – [TRL 3, 4] ▪ Regenerable TCCS – [TRL 4] ▪ ISRU ▪ Bioregenerative
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Green	Yellow	Red
Justification/Rationale for Risk	[All]: The inability to control and condition the atmosphere and maintain the makeup & composition, limits the ability of the crew to perform basic functions and can present an immediate threat to the health, life and success of crew and mission. [Moon]: No rapid return capability (days) [Mars]: No rapid return capability (months)		
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
43a.	What system will meet all the requirements for controlling atmospheric pressure, O2 and C02 partial pressure? [ISS 1, Moon 1, Mars 1]		
43b.	What method for recovering O_2 from CO_2 is most effective in an integrated ECLS? [ISS 2, Moon 2, Mars 2]		
43c.	What is the proper trace contaminant load and performance model to drive the design and operation of a trace contaminant system? [ISS 2, Moon 2, Mars 2]		
43d.	What sensors are required to provide environmental data, monitor performance and provide inputs to control systems (AEMC)? [ISS 2, Moon 2, Mars 2]		

43e.	What monitoring and control system can provide semi to total autonomous control of Life Support Systems (AEMC)? [ISS 2, Moon 2, Mars 2]
43f.	How can microbes and candidate crop species be engineered to perform better and fulfill multiple functions in a bioregenerative system? [ISS N/A, Moon 3, Mars 1]
43g.	What are the interfaces between the biological and physical chemical life support subsystems for a specified mission? [ISS N/A, Moon 3, Mars 1]
43h.	Can viability and genetic integrity of the biological components be maintained for the duration of different missions? [ISS N/A, Moon 3, Mars 2]
43i.	What are the effects of radiation on biological components of the life support system? [ISS N/A, Moon 3, Mars 1]
43j.	What research is required to validate design approaches for multiphase flow and particulate flows for air revitalization systems in varying gravity environments? [ISS TBD, Moon TBD, Mars TBD]
Related Risks	Inability to maintain thermal balance in habitable areas
Important References	Space flight Life Support and Biospherics, Eckart, 1996
	Isolation, NASA Experiments in Closed-Environment Living, Advanced Human Life Support Enclosed System Final Report, Volume 104, Science And Technology Series, A Supplement to Advances in the Astronautical Sciences, Edited by Helen W. Lane, Richard L. Sauer and Daniel L. Feeback. Published for the American Astronautical Society by Univelt, Incorporated, P.O. Box 28130, San Diego, CA 92198. web: http://lsda.jsc.nasa.gov/books/ground/chambers.pdf
	Designing for Human Presence in Space: An Introduction to Environmental Control and Life Support Systems, NASA RP-1324, 1994

Risk Title: Maintain Thermal Balance in Habitable Areas

Primary Risk Area	Advanced Life Support (ALS)		
Risk Number	44		
Risk description	Inability to acquire, transport and reject waste heat from life support systems reliably and efficiently with minimum power, mass and volume. Capability is crucial to enabling extended human exploration of space.		
Context/Risk Factors	Sources of heat from other elements of the mission, Orientation of the vehicle during flight, Orientation of vehicle and/or habitat on planetary surface, Location on planetary surface, Planetary environment (temperature ranges & extremes, dust, seasonal variations, etc.), Use or availability of local planetary resources		
Specific current countermeasure(s) or mitigation(s)	Thermal control systems have been a mandatory system on every space vehicle that has ever flown.		
Specific projected countermeasure(s) or mitigation(s)	Several advances are underway to improve the reliability and life, or decrease the mass, volume, or power required for thermal control system hardware. [TRL 3-6]		
Justification/Rationale for Risk	Humans cannot live and work on Mars without a thermally controlled environment.		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Green	Yellow	Red
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
44a.	What heat transport fluids meet the requirements for specified missions? [ISS 1, Moon 1, Mars 1]		
44b.	What materials and designs will meet the heat acquisition (cold plates, heat exchangers, cooling jackets, etc.) requirements for specified missions? [ISS 1, Moon 1, Mars 1]		
44c.	What materials and designs will meet the heat transport (pumps, two-phase loops, heat pumps, etc.) requirements for specified missions? [ISS 1, Moon 1, Mars 1]		
44d.	What materials and designs will meet the heat rejection (radiators, sublimators, evaporators, etc.) requirements for specified missions? [ISS 1, Moon 1, Mars 1]		
44e.	What materials and designs will meet the humidity control requirement requirements for specified missions? [ISS 1, Moon 1, Mars 1]		
44f.	What thermal system sensors will meet the requirements to provide monitoring and data collection for specified missions? (AEMC) [ISS 2, Moon 2, Mars 2]		
44g.	What monitoring and control system hardware and design will meet the requirements for specified missions? (AEMC) [ISS 2, Moon 2, Mars 2]		
Related Risks	TBD		
Important References	Space flight Life Support and Biospherics, Eckart, 1996		
	Isolation, NASA Experiments in Closed-Environment Living, Advanced Human Life Support Enclosed System Final Report, Volume 104, Science And Technology Series, A Supplement to Advances in the Astronautical Sciences, Edited by Helen W. Lane, Richard L. Sauer and Daniel L. Feeback. Published for the American Astronautical Society by Univelt, Incorporated, P.O. Box 28130, San Diego, CA 92198. web: http://lsda.jsc.nasa.gov/books/ground/chambers.pdf		
	Designing for Human Presence in Space: An Introduction to Environmental Control and Life Support Systems, NASA RP-1234, 1994		

	Advanced Technology of Human Support in Space, Committee on Advanced Technology for Human Support in Space, Aeronautics and Space Engineering Board, National Research Council, National Academy Press, Washington DC, 1997

Risk Title: Manage Waste

Primary Risk Area	Advanced Life Support (ALS)		
Risk Number	45		
Risk description	Inability to adequately process solid wastes reliably with minimum power, mass, volume and consumables. Inadequate waste management can lead to harm to crew health and safety including reduced performance, sickness and death. Inadequate waste management can also lead to contamination of planetary surfaces or significant increases in mission costs in terms of system mass, power, volume and consumables.		
Context/Risk Factors	Remoteness, Crew health/susceptibility to degree of system closure, mission duration, microgravity environment, failure of other systems such as diminished or failed power supply.		
Specific current countermeasure(s) or mitigation(s)	[All missions]: Crew manually compacts waste and/or stores waste in bags. Feces is mechanically compacted. Adsorbents are used for odor control. [ISS]: Waste is returned in the Shuttle for disposal or returned in logistics modules to be destroyed on entry. [Moon and Mars]: Return of waste is unlikely and overboard disposal is not currently developed as an option for a Lunar or Mars mission. Other countermeasures are not currently developed.		
Specific projected countermeasure(s) or mitigation(s)	[ISS]: Current practice though less than optimum may be adequate for the life of ISS. [Moon and Mars]: Provide a system for adequately collecting (TRL 2-9), transporting (TRL-2, currently only manual transportation is conducted by the crew on ISS), processing for storage (TRL 2-9) or resource recovery (TRL 2-4), storing (TRL 2-9) and disposing (TRL 2-9) trash generated (including clothing) throughout the mission, reliably and efficiently with minimum power, mass and volume. Each countermeasure refers to more than one technology, hence the TRL range.		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Green	Yellow	Red
Justification/Rationale for Risk	Inadequate waste management can lead to harm to crew health and safety including reduced performance, sickness and death. Inadequate waste management can also lead to contamination of planetary surfaces or significant increases in mission costs in terms of system mass, power, volume and consumables.		
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
45a.	What system will meet the storage and/or disposal requirements for specified missions? [ISS 1, Moon 1, Mars 1]		
45b.	What system will meet requirements for processing wastes to recover resources for specified missions? [ISS 1, Moon 1, Mars 1]		
45c.	What waste management will handle complex waste streams such as packaging, paper, etc. in order to meet mission requirements? [ISS 2, Moon 2, Mars 2]		

45d.	What waste management will handle medical wastes such as blood, tissues and syringes etc. in order to meet mission requirements? [ISS N/A, Moon 2, Mars 2]
45e.	What system will separate wastes (inedible plant biomass, trash and/or paper, feces, etc.) in order to meet compatibility mission requirements for waste management? [ISS 1, Moon 1, Mars 1]
45f.	What system will meet the requirements for managing residuals for planetary protection? [ISS N/A, Moon 2, Mars 2]
45g.	How can microbes and candidate crop species be engineered to perform better and fulfill multiple functions in a bioregenerative system? [ISS N/A, Moon 3, Mars 1]
45h.	What are the interfaces between the biological and physical chemical life support subsystems for a specified mission? [ISS N/A, Moon 3, Mars 1]
45i.	Can viability and genetic integrity of the biological components be maintained for the duration of different missions? [ISS N/A, Moon 3, Mars 2]
45j.	How do partial and microgravity affect biological waste processing? [ISS N/A, Moon 3, Mars 1]
45k.	What are the effects of radiation on biological components of the life support system? [ISS N/A, Moon 3, Mars 1]
45l.	What sensors are required to monitor performance and provide inputs to control systems (AEMC)? [ISS 2, Moon 2, Mars 2]
45m.	What monitoring and control system can provide semi to total autonomous control to relieve the crew of monitoring and control functions to the extent possible (AEMC)? [ISS 2, Moon 2, Mars 2]
45n.	Could any of the solid waste be recycled in such a way to provide building material for habitability features needed in subsequent phases of the mission? [ISS N/A, Moon 3, Mars 3]
45o.	What research is required to validate design approaches for multiphase flows for solid waste management and resource recovery in varying gravity environments. [ISS TBD, Moon TBD, Mars TBD]
45p.	What resources are required to manage waste disposal as an environmental risks during long and remote missions (from EH)? [ISS TBD, Moon TBD, Mars TBD]
Related Risks	TBD
Important References	Space flight Life Support and Biospherics, Eckart, 1996
	Designing for Human Presence in Space: An Introduction to Environmental Control and Life Support Systems, NASA RP-1324, 1994
	Isolation, NASA Experiments in Closed-Environment Living, Advanced Human Life Support Enclosed System Final Report, Volume 104, Science And Technology Series, A Supplement to Advances in the Astronautical Sciences, Edited by Helen W. Lane, Richard L. Sauer and Daniel L. Feeback. Published for the American Astronautical Society by Univelt, Incorporated, P.O. Box 28130, San Diego, CA 92198. web: http://lsda.jsc.nasa.gov/books/ground/chambers.pdf
	Advanced Technology of Human Support in Space, Committee on Advanced Technology for Human Support in Space, Aeronautics and Space Engineering Board, National Research Council, National Academy Press, Washington DC, 1997

Risk Title: Provide and Maintain Bioregenerative Life Support Systems

Primary Risk Area	Advanced Life Support (ALS)		
Risk Number	46		
Risk description	Inability (with minimal or no re-supply) to provide adequate fresh food products, assimilate carbon dioxide, produce oxygen and recycle solid and liquid wastes at the levels of performance required for a specified mission due to lack of bioregenerative subsystems integrated with other physical and chemical life support systems.		
Context/Risk Factors	Remoteness. Reduced gravity. For some scenarios, reduced atmospheric pressure. For some scenarios, reduced sunlight. Limits on power availability for artificial lighting. Limited availability of water. Effect of radiation on plants.		
Specific current countermeasure(s) or mitigation(s)	Fresh fruit and vegetables included on current resupply missions to ISS. Development of Vegetable Production Unit. Screen acceptable cultivars for space systems.	Development of Vegetable Production Unit for use with partial Gravity. -Telescience and robotic management of cropping systems. Closed system testing (BPC) to identify area requirement for food, water, O_2. Screen / develop acceptable cultivars.	Mixed cropping systems for continuous production under long-duration missions being tested. Conduct long-duration tests to assess reliability. VPU for salad crop production during transit. Atmospheric pressure limitations to production being determined. Develop surface deployable systems. Materials for Martian greenhouse being evaluated. Screen / develop acceptable cultivars.
Specific projected countermeasure(s) or mitigation(s)	Provide Vegetable Production Unit for ISS. (TRL level 5) (CRL 4)	Scale gravity based salad production module to meet all water and partial O_2 and food requirements for surface mission. (TRL 4) Mixed cropping systems for continuous production evaluated (TRL 5) (CRL 6).	Low pressure Martian greenhouse (TRL 3). Integrated Bioregenerative / PC test bed (TRL3, current). Scale system to meet all O_2, CO_2 requirements for surface habitat and meet partial food requirements. (CRL 6).
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Green	Yellow	Red
Justification/Rationale for Risk	Risk to mission success relatively low. Resupply line is short and resources limited for bioregenerative systems. Possible decrease in crew performance without biological systems.	Necessary to sustain long-term habitats on Lunar surface due to distance required for resupply.	Risk to mission success is high. Very high life support requirement masses necessary for Martian habitat. Bioregenerative systems only means of producing food and primary contributor for CO_2 removal, O_2 production and H_2O purification and achieving high degree of autonomy
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
46a.	What are the optimal methods of plant growth for a specified mission, including development of appropriate hardware, management of light, water, nutrients, gas composition and pressure, trace contaminants, horticultural procedures and disease risks? [ISS 2, Moon 2, Mars 1]		
46b.	How can microbes and candidate crop species be engineered to perform better and fulfill multiple functions in a bioregenerative system? [ISS N/A, Moon 3, Mars 1]		

46c.	What mechanized or automated systems are required for planting and harvesting crops and monitoring and control for a specified mission? [ISS N/A, Moon 3, Mars 2]
46d.	Can viability and genetic integrity of the biological components be maintained for the duration of different missions? [ISS N/A, Moon 3, Mars 2]
46e.	What are the interfaces between the biological and physical chemical life support subsystems for a specified mission? [ISS N/A, Moon 3, Mars 1]
46f.	How do partial and microgravity affect plant growth and crop yield? [ISS N/A, Moon 3, Mars 1]
46g.	What are the effects of radiation on biological components of the life support system? [ISS N/A, Moon 3, Mars 1]
46h.	What percentage of crew food needs should be attributed to ALS plant products for specified missions? [ISS N/A, Moon 3, Mars 2]
46i.	What capabilities and associated hardware are required for processing and storing plant products for a specified mission? [ISS N/A, Moon 3, Mars 2]
46j.	Can the plant production rates and ALS functions be sustained for the duration of the mission? [ISS N/A, Moon 3, Mars 1]
46k.	Can plant yields and ALS functions measured during low TRL (fundamental) testing be scaled up for large bioregenerative systems? [ISS N/A, Moon 3, Mars 1]
46l.	What sensors and monitoring systems will be required to measure environmental conditions and crop growth parameters and health for a specified mission (AEMC)? [ISS 3, Moon 3, Mars 2]
46m.	What control system hardware and software technologies will be required to monitor and control crop systems for a specified mission (AEMC)? [ISS 3, Moon 3, Mars 2]
Related Risks	TBD
Important References	Space flight Life Support and Biospherics, Eckart, 1996
	Isolation, NASA Experiments in Closed-Environment Living, Advanced Human Life Support Enclosed System Final Report, Volume 104, Science And Technology Series, A Supplement to Advances in the Astronautical Sciences, Edited by Helen W. Lane, Richard L. Sauer and Daniel L. Feeback. Published for the American Astronautical Society by Univelt, Incorporated, P.O. Box 28130, San Diego, CA 92198. web: http://lsda.jsc.nasa.gov/books/ground/chambers.pdf
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	Advanced Technology of Human Support in Space, Committee on Advanced Technology for Human Support in Space, Aeronautics and Space Engineering Board, National Research Council, National Academy Press, Washington DC, 1997.
	Wheeler, R.M., G.W. Stutte, G.V. Subbarao and N.C. Yorio. 2001. Plant growth and human life support for space travel. *In*: M. Pessarakli (*ed.*), 2nd Edition. Handbook of Plant and Crop Physiology. pp. 925-941. Marcel Dekker Inc., NY
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	Wheeler, R.M., C.L. Mackowiak, G.S. Stutte, N.C. Yorio, L.M. Ruffe, J.C. Sager, R.P. Prince, B.V. Peterson, G.D. Goins, W.L. Berry, C.R. Hinkle and W.M. Knott. 2003. Crop production for Advanced Life Support Systems. Observations from the Kennedy Space Center Breadboard Project. NASA Tech. Mem. 2003-211184. (58 pages).

Risk Title: Provide and Recover Potable Water

Primary Risk Area	Advanced Life Support (ALS)		
Risk Number	47		
Risk description	If there is an inability to provide and recover potable water from human-generated waste waters, then a potable water shortage may exist. Lack of potable water is a risk to crew health.		
Context/Risk Factors	Remoteness, Crew health/susceptibility to degree of system closure.		
Specific current countermeasure(s) or mitigation(s)	- Water recovery system performance monitored - Stored potable water - Resupply possible	- Water recovery system performance monitored - Minimal stored potable water	- Water recovery system performance monitored - Minimal stored potable water
Specific projected countermeasure(s) or mitigation(s)	Redundant systems [TRL 2-8]; Biological systems [TRL 4]; Possibility of in situ resource utilization (cannot assign TRL until presence of water is confirmed)		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Green	Yellow	Red
Justification/Rationale for Risk	Lack of potable water is a health risk.	Lack of potable water is a health risk. Lack of immediate resupply and increased reliance on water recovery systems compounds risk.	Lack of potable water is a health risk. Lack of resupply and increased reliance on water recovery systems greatly compounds risk.
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
47a.	What system meets all requirements for supplying potable water needs? [ISS 1, Moon 1, Mars 1]		
47b.	What mechanisms to collect and transport wastewater meet the mission requirements? [ISS 1, Moon 1, Mars 1]		
47c.	What methods for the removal of organic, inorganic and microbial contaminants in wastewater meet all mission requirements for efficiency and reliability? [ISS 1, Moon 1, Mars 1]		
47d.	What method to store and maintain portability of recycled water meets all requirements for specified missions? [ISS 1, Moon 1, Mars 1]		
47e.	What sensors are required to provide water quality parameters, monitor performance and provide inputs to a control system (AEMC)? [ISS 2, Moon 2, Mars 2]		
47f.	What control system meets all mission requirements (AEMC)? [ISS 2, Moon 2, Mars 2]		
47g.	How can microbes be engineered to perform better and fulfill multiple functions in a bioregenerative system? [ISS N/A, Moon 3, Mars 1]		
47h.	What are the interfaces between the biological and physical chemical life support subsystems for a specified mission? [ISS N/A, Moon 3, Mars 1]		
47i.	Can viability and genetic integrity of the biological components be maintained for the duration of different missions? [ISS N/A, Moon 3, Mars 2]		
47j.	How do partial and microgravity affect biological water processing? [ISS N/A, Moon 3, Mars 1]		
47k.	What are the effects of radiation on biological components of the life support system? [ISS N/A, Moon 3, Mars 1]		
47l.	What research is required to validate design approaches for multiphase flows for Water recovery systems in varying gravity environments? [ISS 1, Moon 1, Mars 2]		

Related Risks	TBD
Important References	Space flight Life Support and Biospherics, Eckart, 1996
	Designing for Human Presence in Space: An Introduction to Environmental Control and Life Support Systems, NASA RP-1234, 1994
	Advanced Technology of Human Support in Space, Committee on Advanced Technology for Human Support in Space, Aeronautics and Space Engineering Board, National Research Council, National Academy Press, Washington DC, 1997
	Isolation, NASA Experiments in Closed-Environment Living, Advanced Human Life Support Enclosed System Final Report, Volume 104, Science And Technology Series, A Supplement to Advances in the Astronautical Sciences, Edited by Helen W. Lane, Richard L. Sauer and Daniel L. Feeback. Published for the American Astronautical Society by Univelt, Incorporated, P.O. Box 28130, San Diego, CA 92198. web: http://lsda.jsc.nasa.gov/books/ground/chambers.pdf

Risk Title: Inadequate Mission Resources for the Human System

Primary Risk Area	Advanced Human Support Technology (AHST)		
Risk Number	48		
Risk description	Lack of low mass, low power, low consumable, highly reliable, low maintenance solutions to human support systems can lead to excessive mission costs.		
Context/Risk Factors			
Specific current countermeasure(s) or mitigation(s)	The Electronic Nose is an attempt to develop a rugged, small, reagentless easy to use monitor, which is intended to be useful without trying to duplicate the capabilities of a laboratory analytical bench instrument.		
Specific projected countermeasure(s) or mitigation(s)	Second Generation Electronic Nose Sabatier, Med checklist, VPCAR	New area, TBD	New area, TBD
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Yellow	Red	Red
Justification/Rationale for Risk	Human support and monitoring equipment must be sufficiently low in mass and power requirements to be affordable to launch. Reagents and other system consumables needs must be low and nonhazardous. Crew training and maintenance must be low, or the human support technology will not be used properly, increasing the risks. Anecdotal evidence suggests that crew training may be behind the difficulties in water sampling and analysis—some are able to figure out how to remove bubbles; others are not.	Human support equipment must be sufficiently low in mass and power requirements to be affordable to launch. Reagent and other consumable needs must be low and nonhazardous. Crew training and maintenance must be low, or the technology may not be used properly. Analytical capability must be provided in situ, because samples can't be returned to Earth readily	Human support equipment must be sufficiently low in mass and power requirements to be affordable to launch. Reagent and other consumable needs must be low and nonhazardous. Crew training and maintenance must be low, or the technology may not be used properly. Analytical capability must be provided in situ, because samples can't be returned to Earth .

Enabling Questions [Priority on scale of 1 (high) to 5 (low)]	
48a.	What technologies can meet expected mission requirements for both monitoring and efficiency? [ISS 1, Moon 1, Mars 1]
48b.	How is the total mass of the EVA system reduced significantly (portable life support system and the pressure garment? [ISS 2, Moon 2, Mars 2]
48c.	What is the best method for minimizing space suits consumables through advanced subsystems designs (thermal control, CO2 removal, humidity control, trace contaminants)? [ISS 2, Moon 2, Mars 2]
48d.	How do we increase reliability and maintainability of space suits? [ISS 1, Moon 1, Mars 1]
48e.	What levels of hardware, software and operations commonality are desirable and feasible to enhance likelihood of mission success and reduce mission mass, risk and cost? [ISS 2, Moon 2, Mars 2]
48f.	How can the effectiveness, efficiency and safety of integrated human systems in space missions be measured and analyzed (Supports SHFE)? [ISS 1, Moon 1, Mars 1]
48g.	What food system technology selection criteria will be used to effectively reduce critical resources such as air, water, thermal, biomass and solid waste processing, during a mission? [ISS 2, Moon 2, Mars 2]
Related Risks	No Integrated Testing Results in Technical Risks
Important References	Advanced Technology for Human Support in Space, National Research Council Report, 1997. Downloadable from http://peer1.nasaprs.com/peer_review/prog/nap.pdf
	AEMC Technology Development Requirements (1998) downloadable from http://peer1.nasaprs.com/peer_review/prog/prog.html

Risk Title: Mismatch Between Crew Physical Capabilities And Task Demands

Primary Risk Area	Space Human Factors Engineering (SHFE)
Risk Number	49
Risk description	Human performance failure due to habitats, work environments, workplaces, equipment, protective clothing, tools and tasks, not having been designed to accommodate human physical limitations, including changes in crew capabilities resulting from mission and task duration factors, leading to loss of mission, crew injury or illness, or reduced effectiveness or efficiency in nominal or predictable emergency situations. The direct cause of these failures is a mismatch between physical characteristics and capabilities (such as strength, stamina and dexterity) and task demands (such as fit, reach, force, speed and accuracy requirements)
Context/Risk Factors	Gravitational loads, temporal factors, lack of exercise and specific training countermeasures, design constraints. Human physical performance capability deteriorates with lack of stimulation (such as gravity and practice), under adverse physical contexts (stabilization, restrictive clothing, thermal stress etc.) and under task stress conditions that lead to fatigue, sleep loss etc.
Specific current countermeasure(s) or mitigation(s)	Crew training. Crew 'resiliency' Partially appropriate design
Specific projected countermeasure(s) or mitigation(s)	Measurement, analysis, modeling and design tools for optimizing environment, habitat, workplace, equipment, protective clothing and task design. [TRL 2] Tools for analyzing physical tasks to determine allocations of functions between humans and machines. [TRL 2]

Design Reference Mission	ISS	Lunar	Mars
RYG Risk Assessment	Green	Yellow	Red
Justification/Rationale for Risk	[ISS]: Crew accommodations are designed based primarily on volume and mass considerations. Anecdotal information from crew reports and extrapolations from physiological studies is available on impacts of habitats, work environments, workplaces, equipment, protective clothing, tools and tasks on human performance in space contexts. There is inadequate data on physical performance changes in strength, stamina and motor skill as functions of time in micro-g. Returning crewmembers usually exhibit substantial physical and motor deficits. [Moon]: Very limited anecdotal information is available on impacts of habitats, work environments, workplaces, equipment, protective clothing, tools and tasks on human performance in lunar contexts. There is inadequate data on physical performance changes in strength, stamina and motor skill as functions of time in reduced G and while wearing protective clothing. [Mars]: No information is available on impacts of habitats, work environments, workplaces, equipment, protective clothing, tools and tasks on human performance in long-duration space contexts. There is minimal data on physical performance changes in strength, stamina and motor skill as functions of time in reduced-g.		
Enabling Questions [Priority on scale of 1 (high) to 5 (low)]			
49a.	What are the effects of microgravity, 1/6 gravity, or 1/3 gravity on requirements for habitable volume and architecture? [ISS 2, Moon 2, Mars 2]		
49b.	What designs of workspace, equipment, tool and clothing will accommodate differences in crew anthropometry? [ISS 2, Moon 2, Mars 2]		
49c.	What are the effects of duration of exposure to microgravity, 1/6 gravity, 1/3 gravity on human physical performance? [ISS 1, Moon 1, Mars 1]		
49d.	What tools, equipment and procedures will enable crew physical performance to accommodate the effects of exposure to different gravity levels? [ISS 2, Moon 2, Mars 2]		
49e.	How can crewmembers and ground support personnel detect and compensate for decreased physical readiness to perform during a mission? [ISS 2, Moon 3, Mars 3]		
49f.	What scheduling constraints are required to reduce the risk of human performance failure due to physical fatigue to an acceptable probability? [ISS 2, Moon 2, Mars 2]		
49g.	What principles of task design and function allocation will result in operations concepts that meet crew performance requirements for the mission? [ISS 2, Moon 2, Mars 2]		
49h.	What limitations are required on physical workload to enable crewmembers to complete physical tasks with an acceptable probability? [ISS 1, Moon 1, Mars 1]		
49i.	What crew size, composition and task allocations are required to accomplish the design reference missions? [ISS 1, Moon 1, Mars 1]		
49j.	What design considerations are needed to accommodate effects of changes in gravity, including launch, reentry, lunar landing, lunar launch, Mars landing, Mars launch, and Earth return? [ISS 1, Moon 1, Mars 1]		
Related Risks	No Integrated Testing Results in Technical Risks		
Important References	*Human Space flight: Mission Analysis and Design*, eds. W.J. Larson, L.K. Pranke. McGraw Hill Space Technology Series. 1999.		
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	An Ergonomics Case Study: Manual Material Handling in Microgravity. M. Whitmore & T. D. McKay. *Advances in Industrial Ergonomics and Safety VI.* London: Taylor & Francis. 1994.

Risk Title: Mis-assignment of Responsibilities within Multi-Agent Systems

Primary Risk Area	Space Human Factors Engineering (SHFE)		
Risk Number	50		
Risk description	If multi-agent systems, including ground support, crew members and intelligent devices, are designed and assigned functions and responsibilities without due regard to human capabilities and limitations, mission degradation or failure will result. Various combinations of agents are required to accomplish mission objectives. Designing hardware, software and tasks without due regard to necessary combinations of actors will result in problems ranging from inefficiency to loss of mission or loss of life.		
Context/Risk Factors	Risk of failure to successfully perform multi-agent tasks increases with time since training, and with decrements in communications. Lag times of 20 minutes, or communications blackout, can remove one potential agent (Mission Control). Very long crew return times requiring a 'stand and fight' response to any malfunction on the lunar or Mars surface increases the likelihood and severity of consequences of failure to complete tasks due to inadequate task design and planning.		
Specific current countermeasure(s) or mitigation(s)	None – task allocations are made on *ad hoc* basis; crewmembers serve as backup to any automated systems.		
Specific projected countermeasure(s) or mitigation(s)	Tools for analyzing task requirements; reliability measures and data for human performance [TRL 2]. Requirements for use of automated systems and for human-centered system design [TRL 2].		
Design Reference Mission	**ISS**	**Lunar**	**Mars**
RYG Risk Assessment	Yellow	Yellow	Red
Justification/Rationale for Risk	Inadequate design of human-automation systems is known to leads to human error, based on analysis of incidents in the nuclear power industry and commercial aviation. (Ev. Level 3) "Mode error" has resulted in fatal accidents in commercial aviation. (Ev Level 2) At least two critical collisions between ISS and SRMS have been avoided only by real-time monitoring and intervention by MCC. (Level 4)		

Enabling Questions [Priority on scale of 1(high) to 5 (low)]	
50a.	What crew size and composition is required to accomplish the design reference mission (Shared – Integrated Testing supports)? [ISS 2, Moon 1, Mars 1]
50b.	What principles and algorithms for allocating tasks to human crewmembers, ground support and onboard automated systems will reduce the probability of significant errors (Shared – Integrated Testing supports)? [ISS 1, Moon 1, Mars 1]
50c.	What automated tools and equipment are required to enable the crewmembers to accomplish the mission? [ISS 2, Moon 2, Mars 2]
50d.	How do crew size, communications restrictions, crew skills, scheduling constraints and design reference mission task requirements affect the requirements for automation? [ISS 1, Moon 1, Mars 1]
50e.	What combinations of crew, ground and on-board automation capabilities will increase the likelihood of a successful mission (Shared – Integrated Testing supports)? [ISS 1, Moon 1, Mars 1]
50f.	What training and operational readiness assurance processes and implementations will increase likelihood of mission success? [ISS 2, Moon 2, Mars 2]
50g.	What principles of task assignment workload and automation need to be developed to facilitate critical team performance? [ISS 2, Moon 2, Mars 2]
50h.	What tools and procedures are needed to determine the appropriate level of automation and crew control for the various tasks in the design reference mission? [ISS 1, Moon 1, Mars 1]
Related Risks	No Integrated Testing Results in Technical Risks
Important References	*Human Space flight: Mission Analysis and Design*, eds. W.J. Larson, L.K. Pranke. McGraw Hill Space Technology Series. 1999.
	"Collision In Space", S. R. Ellis. *Ergonomics in Design,* Winter, 2000, pp. 4-9.
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APPENDIX C: CROSSCUTTING AREA ROADMAPS AND SCHEDULES

Bioastronautics Critical Path Notional Schedule

ID	Task Name
1	Bioastronautics Critical Path Integrated Schedule
2	Radiation
3	Lunar Astronaut Radiation Exposure Limits
4	Shielding Requirements for Lunar CEV
5	Operational Dosimetry for Development – Phase C/D
6	Mars Radiation Exposure Limits
7	Shielding Requirements for Mars
8	HAC
9	Monitor Nutritional Status
10	0-g Countermeasure Validation
11	Artificial Gravity In-Space Demonstration
12	Partial-g Countermeasure Demonstration
13	Validate Health Requirements for Planetary Surface Activity
14	Medical Care
15	ISS Proof-of-Concept Autonomous Medical Care
16	Lunar Validation of Autonomous Medical Care
17	ISS Clinical Status Evaluation
18	Behavioral Health and Performance
19	Countermeasures Validated on ISS
20	Updated Mars Behavioral Medicine Aerospace Standards
21	Requirements for Lunar CEV
22	Requirements for Mars CEV & Habitats
23	AHST
24	Advanced Surface EVA Test
25	Advanced Food Systems Upgrade
26	Lunar CEV Advanced Life Support Integrated Test
27	Lunar CEV Human Factors Test
28	Mars CEV Advanced Life Support Integrated Test
29	Mars CEV Human Factors Test

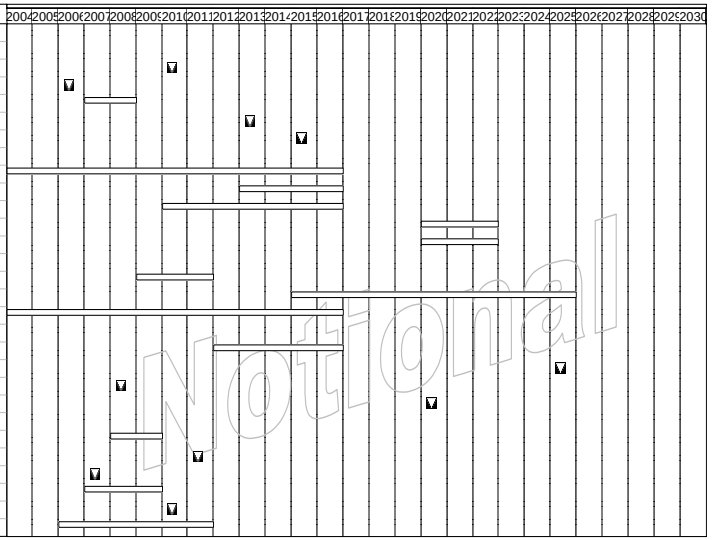

Figure C-1 BCPR Nominal Schedule

Human Adaptation and Countermeasures Notional Schedule

ID	Task Name
1	Human Adaptation and Countermeasures - Moon / Mars
2	Shuttle To Be Retired
3	ISS To Be Retired
4	Monitor Clinical and Nutritional Status
5	Exercise
6	Countermeasure Hardware Development
7	Phase A: Requirements Definition
8	Phase B: Design, Development and Review
9	Phase C: Manufacture (Training & Flight Articles), Test and Verify on Ground, Using Bed Rest
10	Phase D: Flight Integration
11	Phase E: Operations
12	Research Protocol Development
13	Exercise Countermeasure Protocol Requirements & Methodology Definiti
14	Exercise Countermeasure Protocol Design, Development, Review & Validation on Ground
15	Test and Verify Exercise Protocol in Flight (ISS)
16	Validate and Refine Exercise Protocol (ISS)
17	"Validate Optimal Set of Combined Countermeasures (Exercise, Pharmacology, Nutrition, and AG) Protocols - ISS"
18	Pharmacological and Nutritional Countermeasures
19	Develop Pharmacological Countermeasures Project Plan
20	Form Team, Write Plan, Develop Budget, Non-Advocate Review
21	Drug Interaction Studies
22	Consult Experts & Conduct Simulations to Look for Deleterious Drug Interactions
23	Develop Pharmacodynamics/Pharmacokinetics Protocols
24	Use Simulations (eg Bed Rest) to Develop & Test Methodologies for Space Studies
25	Test Pharmacokinetics in Space
26	Implement Studies in Flight Queue and Initiate New Studies
27	Test Individual Pharmacological Countermeasures on ISS
28	Examine Individual Drugs Without Exercise or AG
29	Develop Nutritional Project Plan
30	Define Nutritional Requirements in Space
31	Test Nutritional Countermeasures in Space
32	Test Integrated Pharmacological and Nutritional Countermeasures on ISS
33	Validate Optimal Set of Combined Countermeasures (Exercise, Pharmacology, Nutrition, and AG) Protocols - ISS
34	Artificial Gravity
35	AG Non-Advocate Review
36	International Ground Based Simulations of Short Arm Centrifuge (SAC)
37	Requirements for Flight SAC
38	Build Flight SAC
39	Launch SAC
40	Test AG Countermeasures
41	ARC Refurb for Long Arm Centrifuge (LAC)
42	Live Aboard Study Solicitation for LAC
43	Studies for LAC
44	NRA for LAC
45	Adaptation Studies
46	LAC Testing
47	Mars Vehicle Design
48	Decision Point for Integrated Countermeasure Package
49	Validate Optimal Set of Combined Countermeasures (Exercise, Pharmacology, Nutrition, and AG) Protocols - ISS

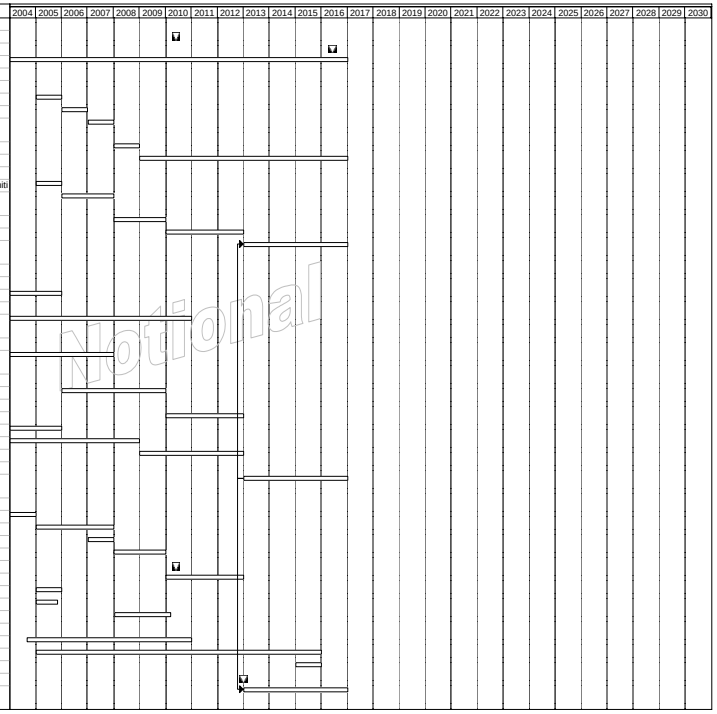

Figure C-2 HH&C Nominal Schedule

Space Radiation Health Notional Schedule

ID	Task Name
1	Space Radiation Health
2	Lunar Radiation
3	Lunar Astronaut Radiation Exposure Limits
4	Radiology Research at NSRL to Define Risks and Reduce Uncertainty
5	Verification of Lunar Radiation Environment (Precursor Missions)
6	Integrated Risk Prediction Model (JSC Product, Based on Research Result
7	Astronaut Exposure Limits for Lunar Missions (Recommended by NCRP)
8	CEV Requirements
9	Phase 1 Shielding Requirements for CEV
10	Verification of CEV Shielding
11	Phase 2 Shielding Requirements for CEV (Based on Verification Results)
12	Lunar Habitat Requirements
13	Shielding Requirements for Lunar Habitat & Lunar Surface Activities (LSA)
14	Operational Dosimetry for Lunar Habitat
15	Evaluation of Habitat Shielding
16	Shielding Measurements of Lunar Regolith
17	Lunar Surface Activity Requirements
18	Solar Particle Event (SPE) Model
19	LSA Radiation Requirements (Suit Shielding & In Suit Active Dosimetry)
20	Integrated Risk Prediction Model
21	SPE Warning Requirements & Forecasting Requirements
22	Clinical Requirements for Radiation Countermeasures
23	Training Requirements for Crew, Ground Controllers, Flight Surgeons
24	UV and Ionizing Radiation Interaction Studies
25	UV Shielding Requirements
26	Operational Dosimetry Development (for Robotic Precursors, CEV, Lunar Habi
27	Phase A
28	Phase B
29	Phase C/D
30	Mars Radiation
31	Mars SPE Forecasting and Warning
32	Requirements for Mars SPE Warning & Solar Max & Min Radiation Environ
33	Mars Solar Max Radiation Environmental Survey (Orbiting & Surface Dosim
34	Mars Solar Min Radiation Environmental Survey (Orbiting & Surface Dosim
35	Mars SPE Warning System Operational
36	Mars SPE Warning System Validated
37	Mars Systems
38	Requirements for Habitat Dosimetry, Vehicle Shielding, Vehicle Dosimetry
39	Phase 2 Integrated Risk Prediction Model
40	Mars Radiation Exposure Limits
41	Mars Surface Suit Shielding Requirements
42	Mars Habitat Shielding Requirements
43	Analysis of Mars Regolith Shielding Properties
44	Radiation Protection Research for Mars
45	Upgrade NSRL for Mars Radiobiology Studies
46	Second Beam Line For Dose Fractionation, Chronic Radiation Biology Stud Phase 2 Physics Data Base (Test Structures and Subsystems)
47	Expand Laboratories
48	Drug Discovery Program
49	Space Radiobiology to Validate Terrestrial Predictions (ISS, Russian Free-Flyers,

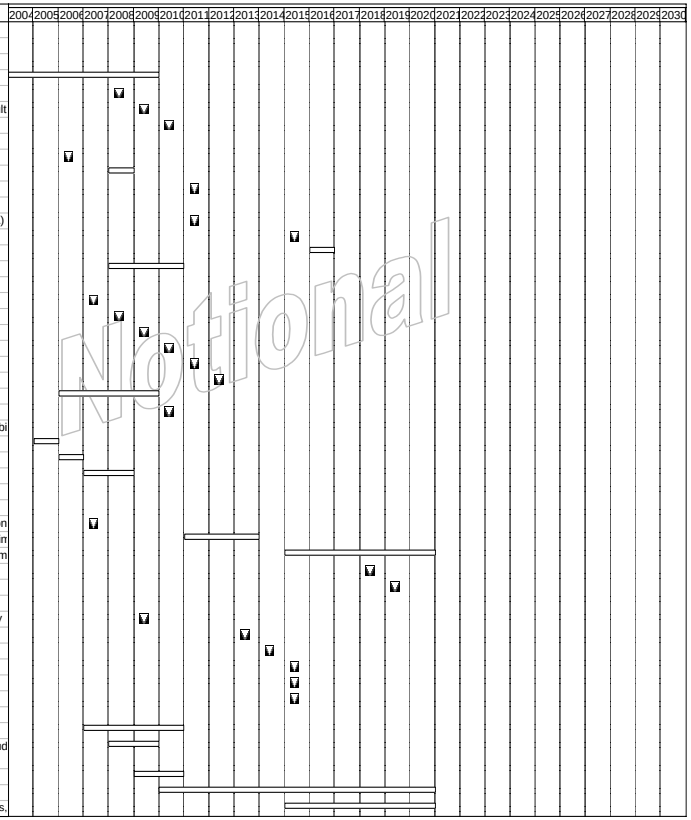

Figure C-3 Radiation Health Nominal Schedule

Behavioral Health and Performance Notional Schedule

ID	Task Name
1	Behavioral Health & Performance
2	BH&P Plan
3	Form Integrated BH&P Product Team
4	Develop BH&P Project Plan (Includes Activities & Lunar/Mars Test Facility)
5	Conduct BH&P Non-Advocate Review
6	Approve and Find Plan for Implementation
7	Design and Develop BH&P Monitoring & Diagnostic Tools (e.g., Group Dynamics, Workload/Scheduling, Cogntive & Physical Performance, Neurobehavioral Health, Training and Communications)
8	Develop and Test Components in Relevant Environments or Testbeds
9	Prototype Testing of Components in Space
10	Test Tools in Integrated Ground Facility
11	Test Tools on ISS
12	Test Subsystems in High Fidelity Integrated Facility
13	Flight Validate and Verify Tools (TRL 9)
14	BH&P Countermeasures
15	Development of Predictive Models
16	BH&P Research on Long Term Effects Using Ground Analogs
17	Development and Testing of Intervention & Treatment Protocols on Ground
18	Test and Verify Protocols in Flight (ISS) Including Individual Treatment and Support Protocols
19	Validate Optimal Set of Behavioral Health Protocols - ISS
20	Provide Updated Behavioral Medicine Aerospace Standards for Moon
21	Refine Protocols for Mars Transit Vehicle and Martian Surface Activities
22	Validate Protocols on Lunar Surface
23	Provide Updated Behavioral Medicine Aerospace Standards for Mars
24	Crew BH&P Select-out Criteria for Individuals and Teams
25	Identification & Testing of Criteria in Analog Environments
26	Individual & Crew Compositions Requirements for Lunar Mission
27	Testing & Verification of Individual & Crew Composition Requirements on Lunar Surface
28	Individual & Crew Composition Requirements for Mars Mission
29	BH & P Crew Training Systems
30	Development and Testing of Components in Relevant Ground Labs
31	Test Subsystems in High Fidelity Integrated Facility
32	Test Components in Space
33	Validate Subsystems and Systems on ISS
34	Refine and Validate Systems on Lunar Surface
35	Deliver Integrated Crew Training Systems for Mars Mission
36	Requirements for Crew Surface Habitats and Transit Vehicles (Advanced Tools, High Fidelity Mock-up) for Human Factors, Sleep/Scheduling, Interfaces
37	Develop Prototypes on Ground
38	Test Prototypes in Space Environments (TRL 7, 8, 9)
39	Validate Subsystems in Space
40	Flight Proven Systems Demonstrated in Flight
41	Test & Verify on Lunar Surface
42	Deliver BH&P Requirements for CEV
43	Deliver BH&P Requirements for Mars Transit Vehicle
44	Deliver BH&P Requirements for Mars Habitat

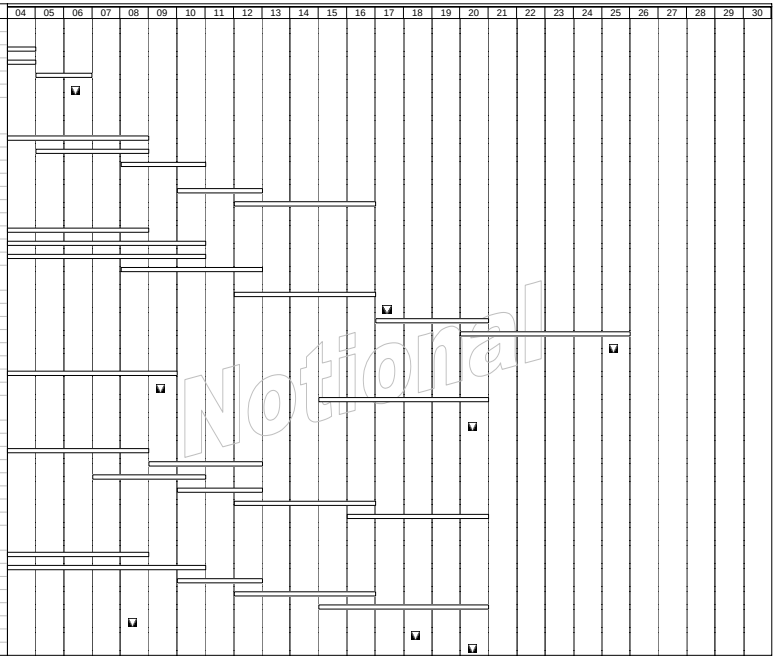

Figure C-4 BH&P Nominal Schedule

Medical Care Notional Schedule

ID	Task Name
1	Autonomous Medical Care Systems
2	Autonomous Medical Care Systems Integrated Project Plan
3	Form Integrated AMCS Project Team
4	Develop AMCS Project Plan
5	Conduct AMCS Non-Advocate Review
6	Fund & Implement Plan
7	Determine AMCS Requirements
8	Develop Requirements for Lunar Mission
9	Develop Requirements for Mars Transit Vehicle and Surface Activities
10	Needs Assessment/Gap Analysis
11	Trade Studies for AMCS (e.g., Hyperbaric Treatment Facility)
12	Develop Integrated Ground-based Facility to Develop & Test AMCS
13	Test Efficacy of Individual Components of Monitoring and Diagnostic Tools and Capabilities
14	Test Efficacy of Subsystems for Monitoring and Diagnoses
15	Test Efficacy of Integrated Systems for Monitoring and Diagnoses
16	Simulated Proof-of-Concept for AMCS on ISS
17	Test Monitoring & Diagnotic Capabilities on ISS (TRL 5-7)
18	Flight Qualify/Demonstrate Efficacy Capabilities (TRL 8)
19	Flight Validate and Verify Capabilities (TRL 9)
20	Validation of AMCS on Lunar Surface
21	Clinical Testing of Protocols and Devices
22	Develop Prototypes on Ground
23	Test Prototypes in Space Environments (TRL 7)
24	Validate Subsystems in Space (TRL 8)
25	Flight Proven Systems Demonstrated in Flight (TRL 9)
26	Test & Verify on Lunar Surface
27	Deliver Requirements for CEV
28	Finalization and Operational Use of Clinical Status Evaluation
29	Acceptable Risk Levels Verified, Baseline Established
30	Revision 1 from Flight Database
31	Revision 2 from Lunar Requirements
32	Revision 3 from Lunar Database
33	Operational Countermeasures

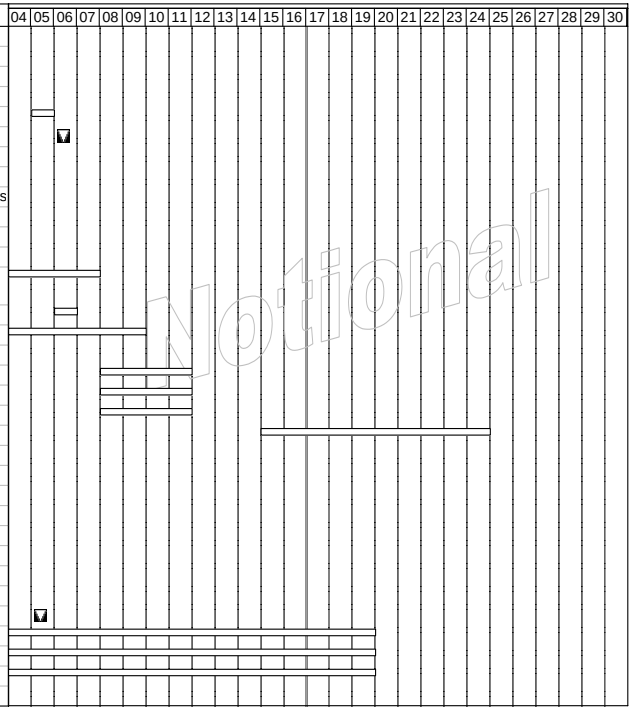

Figure C-5 AMC Nominal Schedule

Advanced Human Support Technology Notional Schedule

ID	Task Name
1	Exploration Systems
2	CEV
3	First Test Flight
4	Operational
5	Lunar Testbed Program
6	Robotic Landings
7	Robotic Landing
8	Robotic Testbed
9	Robotic Testbed
10	Robotic Testbed
11	Robotic Testbed
12	Robotic Testbed
13	Human Landings
14	Human Landing
15	Human Landing
16	Human Landing & Habitat Stay
17	Human Landing & Habitat Stay
18	Mars Robotic & Human Program
19	Robotic Missions
24	First Human Mission (est.)
25	AHST Program
26	BCPR Baseline
27	Knowledge Transfer to Exploration
34	Research & Technology Development
35	Search for Innovation
36	AEMC
37	LTV Monitoring Solutions Development
38	LTV Monitoring Solutions Test
39	LO/MTV Monitoring Solutions Development
40	LO/MTV Monitoring Solutions Test
41	LO/MTV In Situ Analytical Development
42	LO/MTV In Situ Analytical Test
43	LO/MTV In Situ Analytical Upgrade 1
44	LO/MTV In Situ Analytical Upgrade 2
45	LO/MTV Integrated Control Components Development
46	LO/MTV Integrated Control Components Upgrade
47	AEVA
48	Zero G Suit Upgrade Development
49	Zero G Suit Upgrade Test
50	Surface Suit Development
51	Surface Suit Test
52	AFT
53	Stored Food System
54	LTV/LO/MTV/MH Development of stored food system
55	LTV/LO/MTV/MH Stored food system component test
56	LTV/LO/MTV/MH Food system upgrade
57	Crop Integration - Food Processing

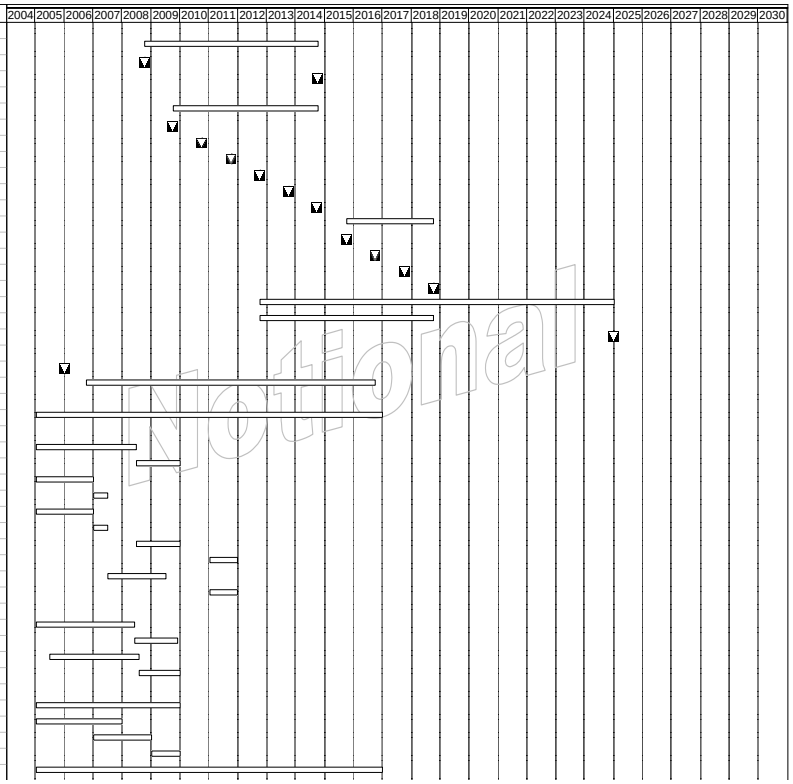

Figure C-6 AHST Nominal Schedule